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ELECTRONIC WARFARE SUPPORT JAMMING
PRE-MISSION ROUTE OPTIMIZATION

Kenneth D. Watts

NAVAL POSTGRADUATE SCHOOL

Monterey, California



THESIS

ELECTRONIC WARFARE SUPPORT JAMMING
PRE-MISSION ROUTE OPTIMIZATION

by

Kenneth D. Watts

June 1977

Thesis Advisor:

H. A. Titus

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ELECTRONIC WARFARE SUPPORT JAMMING PRE-MISSION ROUTE
OPTIMIZATION

by

Kenneth D. Watts
Captain, United States Marine Corps
BSEE, Florida Institute of Technology, 1971

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

from the
NAVAL POSTGRADUATE SCHOOL
June 1977

ABSTRACT

An algorithm is developed to determine an optimum route for an ECM support aircraft. Constraints imposed on the problem include aircraft speed limitations, tolerable exposure of the ECM aircraft to enemy fire, and available jammer assets. A priori information required to implement the program consists only of the hostile electronic order of battle and the strike group route. The program is purposely simplified to enable future transfer to smaller minicomputers available to the electronic warfare squadrons.

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I. INTRODUCTION

A. THE ROUTE PLANNING PROBLEM

In the past, a great deal of effort has gone into development of new airborne electronic warfare equipment. Extensive tests and evaluation of these systems have been conducted to optimize their performance against threat systems. When delivered to the fleet, they truly represent good systems, but it seems that the optimization stops at that time. The systems, with computer assistance, perform well for the situations and environments they are subjected to, but what is often overlooked is the fact that the operator has some control over these situations and environments.

In the airborne ECM support mission, the policy has been to fly one of two profiles; the escort or the stand off route. In the escort role, the ECM aircraft flies in the strike group formation and concentrates his assets on the terminal threat radars. This may be advantageous in some situations, but for the most part, with the threat density and Home-On-Jam (HOJ) capability of current missiles, the ECM aircraft would only serve as a billboard threat magnet and his chances of survival would be slim. Also, after ordnance delivery, he would be unable to keep the speed of the exiting strike group, and the advantage of radar-strike aircraft-jammer alignment would be lost. In the stand off role the ECM aircraft does not penetrate any of the threat envelopes and concentrates his assets

primarily on the wider beamed search and acquisition (ACQ) radars. This is a good tactic where ECM aircraft exposure must be minimized, but good radar-strike aircraft-jammer alignment is sacrificed and excessive range of the jammer occurs.

The modified escort route has been suggested as a compromise between the escort and standoff routes. In this route, the ECM aircraft flies an escort role until a predetermined point where it alters course to avoid high exposure areas and rejoins the strike group on their exit leg. This type mission offers some of the increased performance of the escort role while retaining some of the survivalability of the stand off role.

If presented with a strike route, the EOB, permissible ECM aircraft threat exposure, jammer assets, and speed, the operator can determine a route which maximizes the jamming effectiveness against enemy emitters for these conditions. Current planning documents and tactical manuals give the ECM operator the necessary information to determine the effectiveness against a single radar from any given point. If the operator flies anything other than a pure escort role he must determine which radars to concentrate his assets upon; i.e., he must determine a priority for each emitter. These priorities will change as the strike group progresses along its route. For each position of the strike route the operator must check all possible locations for his jammer platform to come up with the best possible position for his aircraft. He then repeats this process for each position of the strike route, each time re-prioritizing each emitter and checking each possible jammer location to determine his optimum position. When he has performed all these calculations he must select within the aircraft speed limitations, the route for maximum jamming effectiveness. For a moderately dense environment and a simple strike route

it would take an operator days to research all information and perform the calculations necessary to develop an optimum ECM route.

B. PROGRAM DESCRIPTION

The problem of determining an optimum route does not lend itself well to a continuous solution by conventional techniques. Because of the fixed number of jammers on board the aircraft and the rather abrupt lethal envelopes of the threat systems, there arise many sharp discontinuities which defy the continuous solution. In a very short period of time the various emitter priorities can change grossly and jammer assignments should instantly change. As a result of this the problem must be approached as a series of static situations which can be solved within the constraints. An optimum route can then be determined by using dynamic programming techniques [Ref. 1].

A program to accomplish this has been developed. It does not generate the absolute optimum route since this would take far more computer size and time than will be available to the aircrew. Because of the constraint of ECM aircraft maximum speed, a majority of the points calculated in the absolute optimization would have to be discarded anyway, since they could not be reached by the aircraft in the time available. Several approaches to the problem were tried. The method chosen represents a nearly optimum route and is obtained with a small program size and short execution time. Essentially, the program determines the point where the strike group exposure is greatest and for this time computes the absolute optimum position for the jammer platform within its own tolerable exposure limits. It then computes a high performance route to and from this

point. For the typical environment where the strike group exposure increases monotonically to this maximum, the route generated should approach the absolute optimum. It should be pointed out at this time that the program generates a horizontal flight route only. As such, all beam widths and radiation patterns referred to are in the horizontal plane.

The basic program flow is seen in Fig 1 . It is comprised primarily of two parallel paths. The strike route is input as a series of points that are separated by one minute in time. After the allowable jammer positions and the point of highest exposure to the strike group are computed, the ten best positions for the jammer platform are determined from all the allowable positions. Ten was selected as a reasonable number considering the characteristics of the Wang 2200 computer expected to be available to the operator. The strike route is then divided into two segments about the highest exposure point. The program then takes parallel paths for each segment. Starting with the first of the ten possible jammer positions at the high exposure point, a circle with radius equal to the one minute flight distance of the ECM aircraft is drawn. The performance for the next strike route point in the segment is then computed from every point in the circle with the highest being retained as the next ECM route point. This point becomes the center of the circle for the next time slot and the process is repeated. The routes generated for both segments are then joined together to form an ECM route. The performances at each point are summed for a measure of effectiveness (MOE) for the route. A route is generated for each of the ten highest performance jammer positions determined for the strike group's greatest exposure point, and the operator has his choice of the routes based on the MOE.

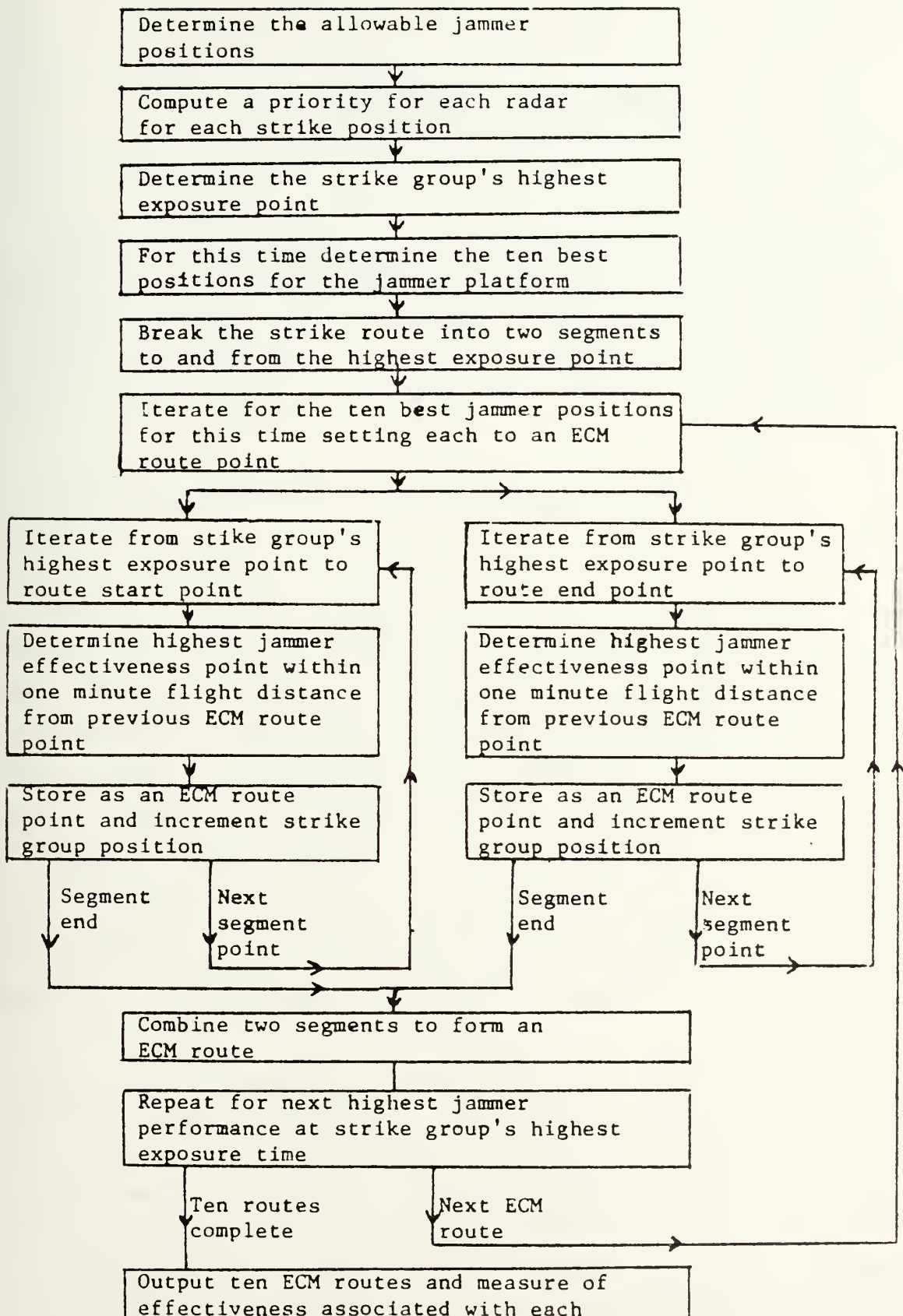


Figure 1 - BASIC PROGRAM FLOW

II. PRELIMINARY CALCULATIONS

Before the jamming effectiveness values are determined, there are some preliminary calculations which must be performed. First, the allowable positions for the ECM aircraft must be defined, and then for each position of the strike route, a priority must be assigned to each emitter.

A. ALLOWABLE POSITIONS FOR THE JAMMER PLATFORM

If there were an unlimited supply of ECM aircraft and crews, there would be no problem determining a route to fly. Every mission would be flown as an escort role and effectiveness would be outstanding until such time as the ECM aircraft was destroyed by HOJ missiles. Such is not the case, however, since these aircraft and their crews are few in number and very expensive. They also lack the flight performance characteristics essential to fly escort with the strike group in a high threat area. It is therefore necessary to restrict the operation of the ECM aircraft to areas of lower exposure to terminal threats.

For this program a pucker factor is used to determine allowable areas of operation. This pucker factor is input by the operator. It is a measure of his permissible exposure to enemy weapons systems. If the pucker factor is zero, then no threat envelopes are penetrated; if it is one, there are no restrictions, and the ECM aircraft may fly through areas where his probability of being hit approaches unity if he is selected as a weapon system target. The pucker factor

may be anywhere in the range zero to one, and the operator is free to select the value he determines to be necessary for the success of the mission.

The probability of a kill vs. range for a typical weapon system is seen in Fig 2. To obtain an approximation of this curve suitable for computer calculations, it was first necessary to generate a curve of probability of survival as a function of range. The model chosen is given by equation (1).

$$P(\text{SURVIVAL}) = \left(\frac{r}{R_L} \right)^n \quad (1)$$

Where:

r = range of aircraft at time of launch

R_L = maximum lethal range of weapon

n = emitter parameter

The parameter n is dependent upon the lethality of the weapon. A plot of this survivability vs. range is seen in Fig 3 with $n = 4$. The low kill probability at the short range is ignored since the aircraft would have to fly through the higher exposure area to reach that point.

KILL
PROBABILITY

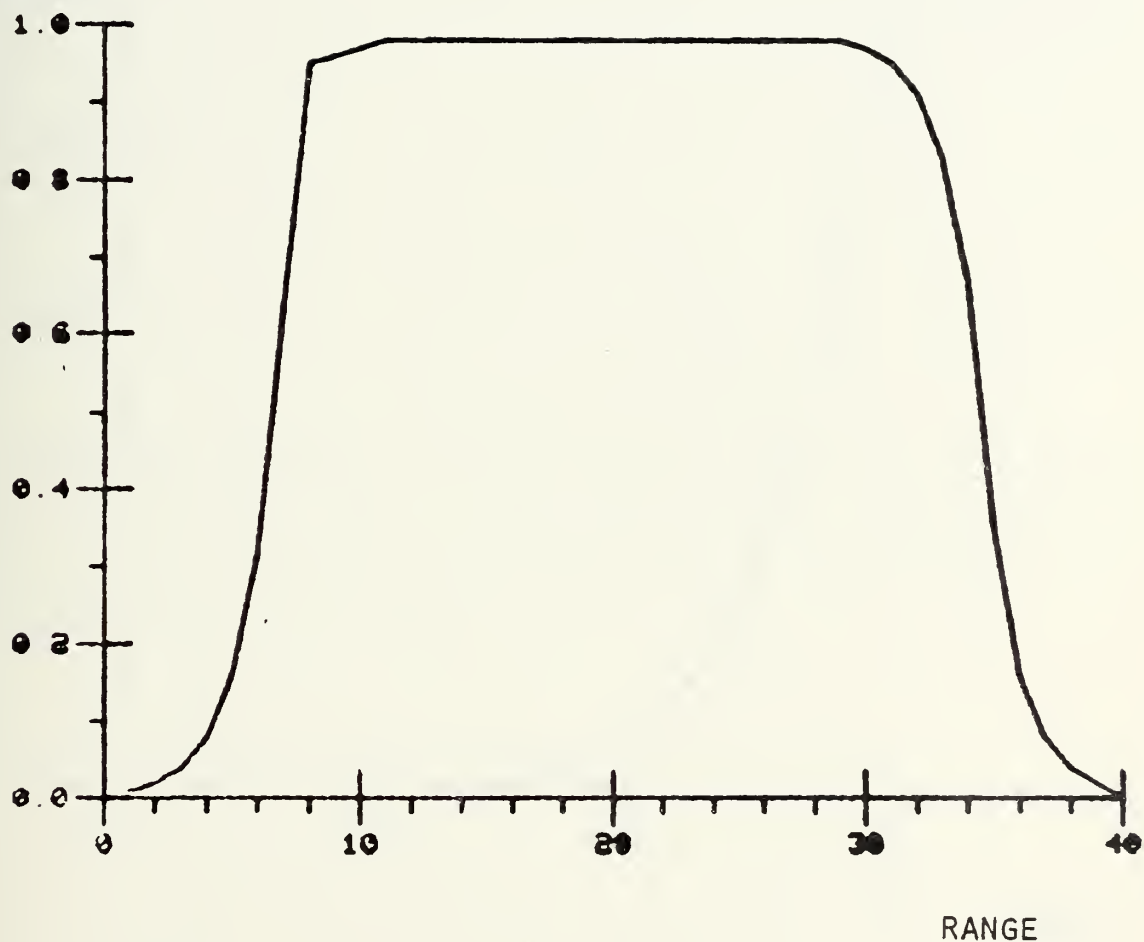


Figure 2 - PROBABILITY OF A KILL BY A HOSTILE WEAPON VS.
THE RANGE OF THE TARGET AIRCRAFT FROM THE WEAPON LAUNCH SITE.

PROBABILITY OF
SURVIVAL

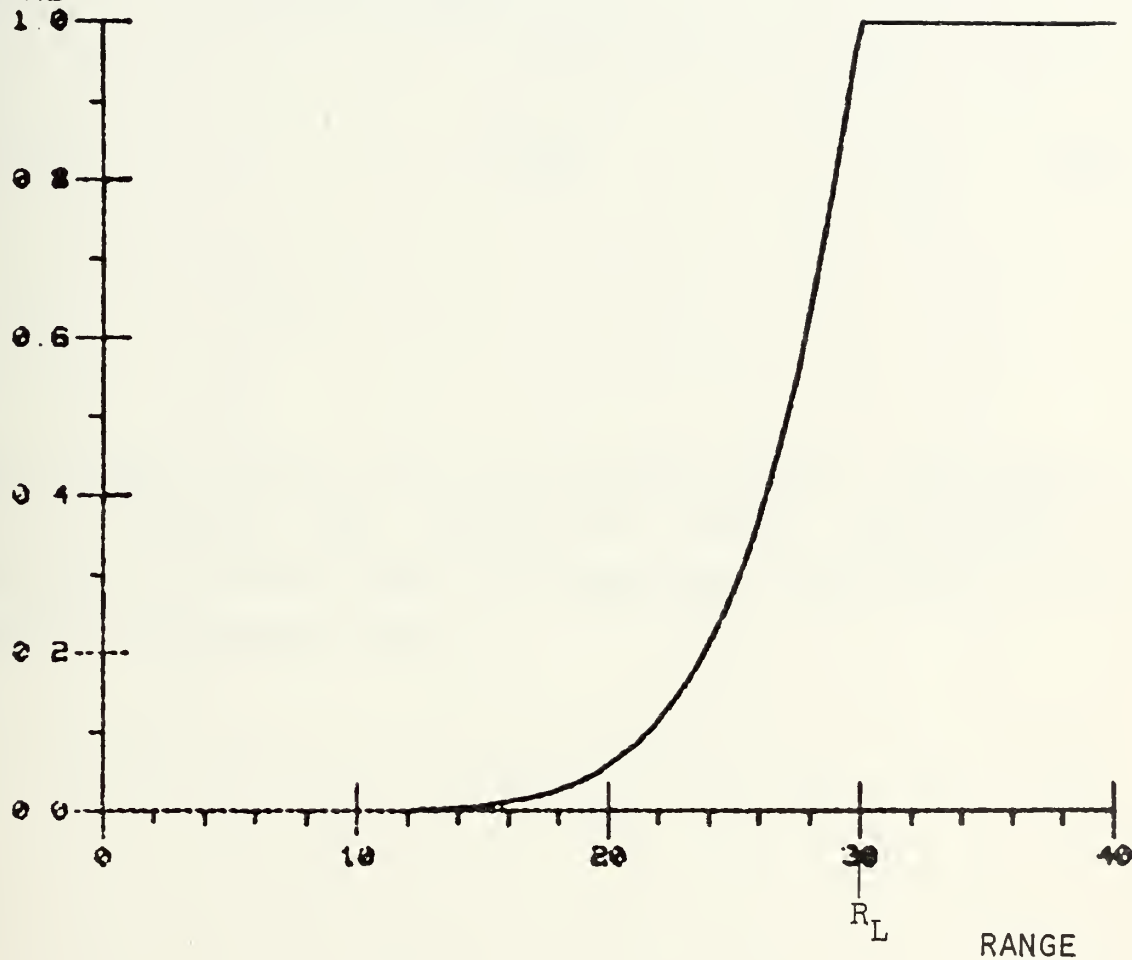


Figure 3 - ASSUMED PROBABILITY OF SURVIVAL AGAINST A
HOSTILE WEAPON VS. THE RANGE FROM THE WEAPON SITE.

The exposure, or probability of kill, becomes:

$$\begin{aligned}\text{EXPOSURE} &= P(\text{KILL}) \\ &= 1 - P(\text{SURVIVAL}) \\ &= 1 - \left(\frac{r}{R_L} \right)^n\end{aligned}\tag{2}$$

Fig 4 shows a plot of the calculated exposure superimposed on the typical kill probability curve. The factor n is selected to give the best fit between the two curves in the area of the greater range.

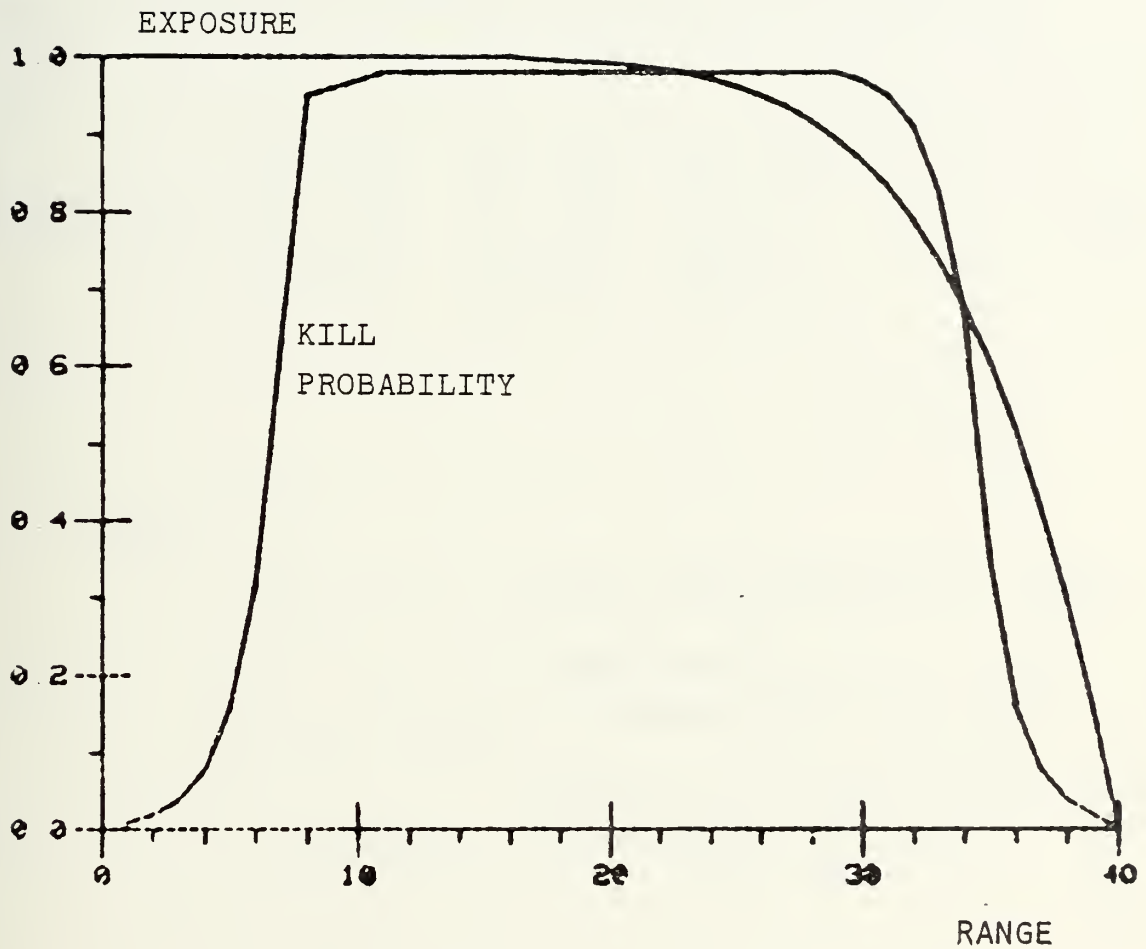


Figure 4 - EXPOSURE TO AND KILL PROBABILITY OF A HOSTILE WEAPON VS. THE RANGE FROM THE WEAPON LAUNCH SITE.

There will be some areas where the aircraft could be within lethal range of multiple weapons systems. In this case, the assumption was made that the probabilities of survival against the individual weapons were independent of each other. The overall survival probability then becomes the product of the individual probabilities given by:

$$P(\text{SURVIVAL}) = \left(\frac{r_1}{R_{L1}} \right)^{n_1} \left(\frac{r_2}{R_{L2}} \right)^{n_2} \left(\frac{r_3}{R_{L3}} \right)^{n_3} \dots \quad (3)$$

Where:

r_1, r_2, r_3 = Range from emitters 1, 2, and 3
respectively

R_{L1}, R_{L2}, R_{L3} = Maximum lethal range of
weapons 1, 2, and 3 respectively

n_1, n_2, n_3 = Stored emitter parameters

The exposure is again equal to:

$$\text{EXPOSURE} = 1 - P(\text{SURVIVAL})$$

$$= 1 - \left[\left(\frac{r_1}{R_{L1}} \right)^{n_1} \left(\frac{r_2}{R_{L2}} \right)^{n_2} \left(\frac{r_3}{R_{L3}} \right)^{n_3} \dots \right] \quad (4)$$

If more threat ranges are penetrated, the exposure will more rapidly approach unity.

A subroutine calculates the exposure for each point in the operating area. If it exceeds the pucker factor then that particular point is thrown out as a possible location for the jammer platform. The routine then deletes points which might have a tolerable exposure but are surrounded by points of higher exposure and therefore inaccessible. The points which remain are returned to the main program as possible route points. If a pucker factor of one is input, then it can be expected that a route close to an escort will be generated, and likewise, a pucker factor of zero will generate a pure stand off route.

B. PRIORITIZATION OF EMITTERS

The next step in determining an ECM route is the prioritization of the emitters. This calculation must be performed for each point in the strike group route. The priority should be zero when the strike group is outside the maximum radar detection range and maximum when the strike passes over the radar. For ease of calculation, a model similar to the exposure model was chosen and is given below.

$$\text{PRIORITY} = P_{\text{max}} \left[1 - \left(\frac{r}{R_{\text{max}}} \right)^n \right] \quad (5)$$

Where:

$P_{\max}$ = maximum priority

$R_{\max}$ = maximum detection range

n = stored emitter parameter

The parameter n is again stored in the parameter table and determines how the priority will roll off as the range approaches $R_{\max}$. Examples of priority vs. range are plotted

in Fig 5 for $n = 2, 3, \text{ and } 4$.

EXPOSURE

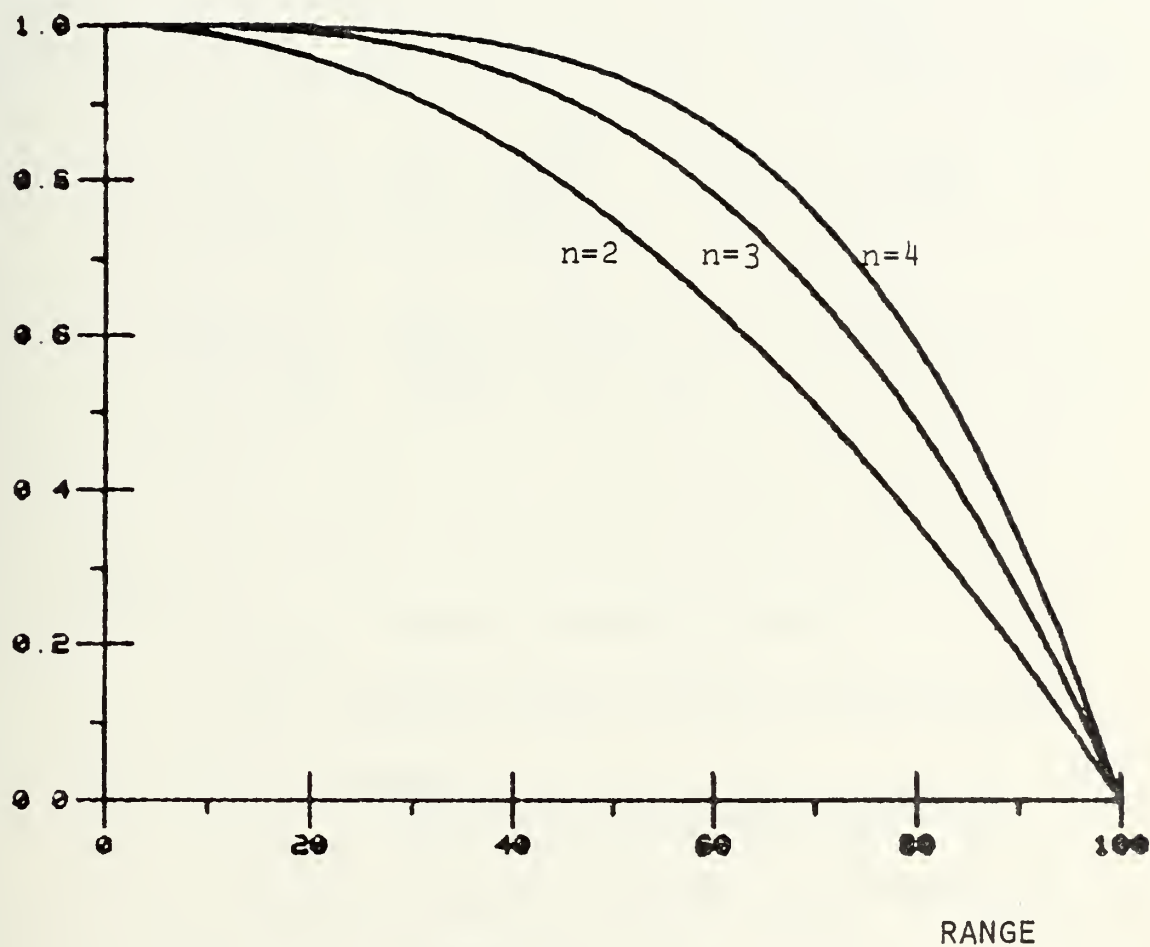


Figure 5 - EXAMPLES OF PRIORITY ASSIGNED TO EMITTERS VS. THE RANGE FROM THE EMITTERS FOR DIFFERENT VALUES OF n .

For radars which control weapons systems, there is a second significant range to consider, that of the maximum lethal range of the associated weapon. The priority of these terminal threat radars is adjusted for distances within this range as below.

$$\text{PRIORITY} = 0$$

$$r > R_{\max} \quad (6)$$

$$= P_{\max} \left[1 - \left(\frac{r}{R_{\max}} \right)^n \right] \quad R_L < r < R_{\max}$$

$$= P'_{\max} \left[1 - \left(\frac{r}{R_L} \right)^m \right] + P_{\max} \quad 0 < r < R_L$$

Where:

$R_{\max}$ = Maximum detection range

R_L = Maximum lethal range of associated
weapon

$P_{\max}$ = Maximum priority when outside R_L

$P'_{\max}$ = Maximum increase in priority when
within R_L

m = Stored emitter parameter

n = Stored emitter parameter

Once again m is a characteristic of the associated weapon and determines how the priority will roll off as the range approaches the maximum lethal range. This factor in addition

to $P_{\max}$, $P'_{\max}$, $R_{\max}$, and R_L are stored in a radar parameter table. An example of a typical priority vs. range is plotted in Fig 6 for $n = 5$, $m = 6$, $R_{\max} = 60$, $R_L = 30$, $P_{\max} = 0.3$, and $P'_{\max} = 0.6$.

The sum of the two terms $p_{\max}$ and $p'_{\max}$ will not exceed one so the priorities will already be normalized. The resultant priority is then indicative of the degree of threat posed by a particular radar at a given range. Fig 7 is a plot of the normalized priority vs. range of three typical radars, a missile control, a gun control, and an acquisition. If all three of these radars were co-located, it can be seen that as the range decreases from one hundred miles to zero, the acquisition starts out as the highest priority and is surpassed by the missile radar as range decreases, and this priority is surpassed by the anti-aircraft artillery (AAA) radar as the lethal gun range is penetrated.

This prioritization scheme is relatively simple and is only a function of range. The constants $P_{\max}$, $P'_{\max}$, n , and m , which are stored can be changed if desired to alter the priority relationships. For the EW/ACQ radars, the value of R_L stored is zero, indicating an associated weapon with zero lethal range; i.e., no directly associated weapon.

PRIORITY

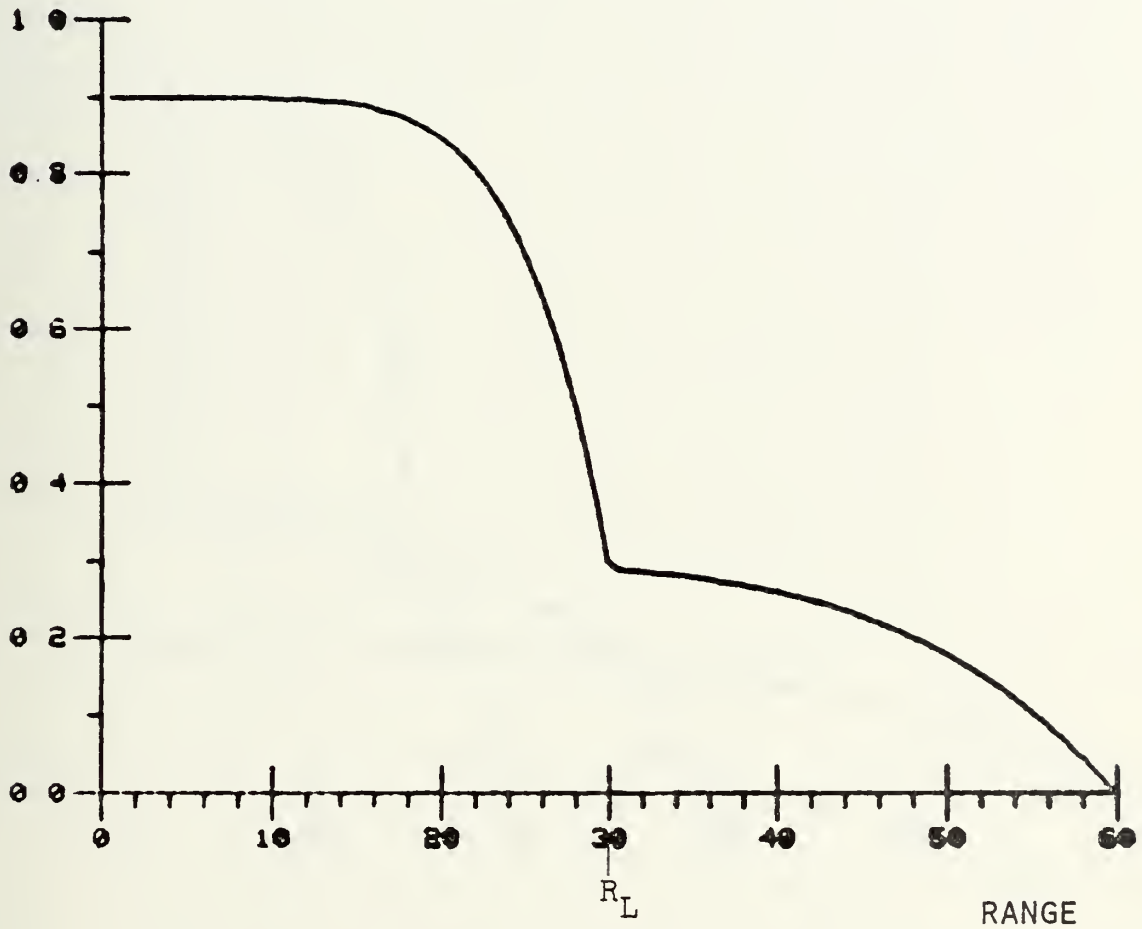


Figure 6 - TERMINAL THREAT RADAR PRIORITY ASSIGNED VS. THE RANGE FROM THE RADAR SITE.

PRIORITY

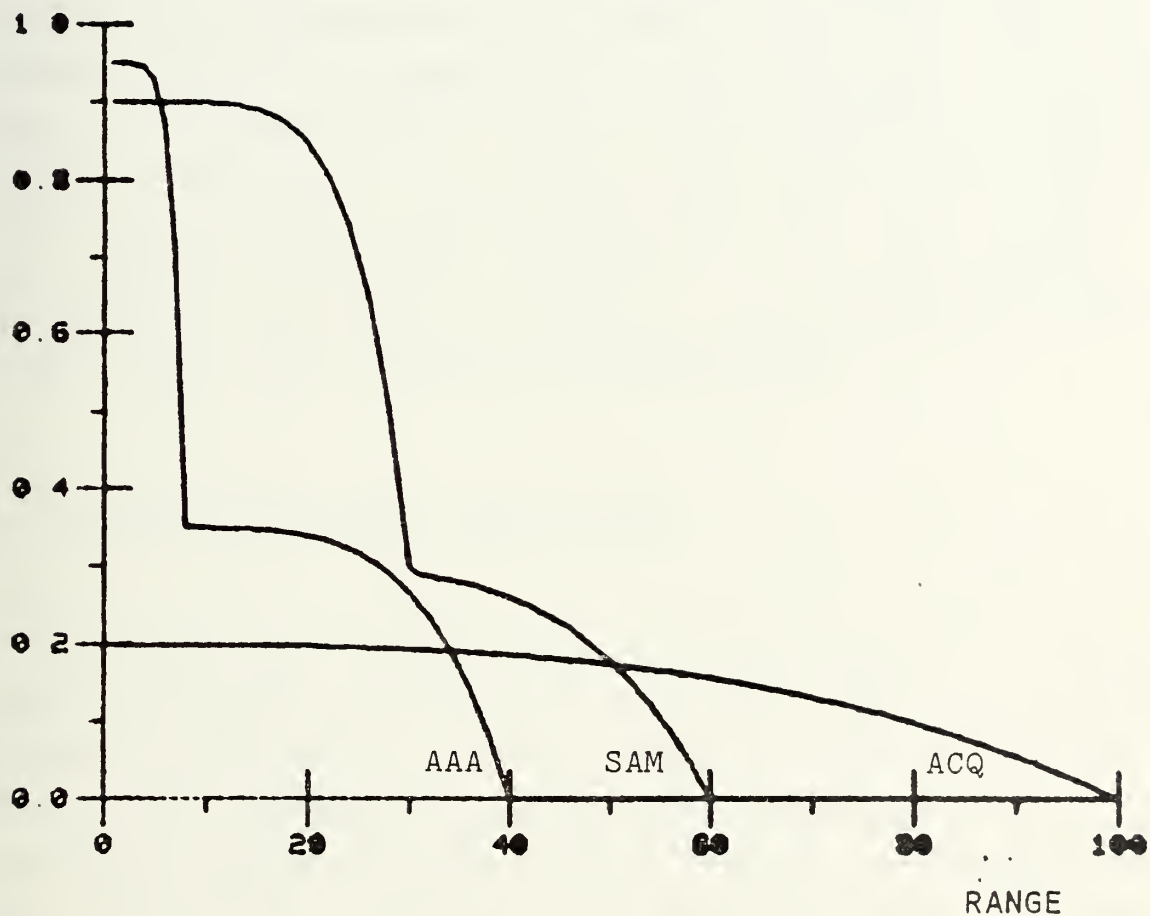


Figure 7 - EXAMPLES OF RELATIVE VALUES OF SAM, AAA, AND ACQ PRIORITY VS. THE RANGE FROM THE RESPECTIVE SITE.

III. JAMMING EFFECTIVENESS DETERMINATION

To determine an optimum route by any method requires a measure of performance for the jammer platform. Given a strike group to protect at any instant of time against an enemy air defense network, with an ECM aircraft of fixed jammer configuration, an operator must have some factor by which he can compare possible locations for his aircraft. The performance measure utilized in this program was a jam-to-signal power ratio weighted by the respective emitter priority and jammer modulation vulnerability.

A. JAM-TO-SIGNAL RATIO CALCULATION

The ratio of jammer power at the receiver to the received signal power (J/S) provides a good performance measure for a jammer. Since the jammer is fixed in power, if the J/S is computed for the different possible positions of the jammer platform, it will give a relative indication of the effectiveness against that particular radar from each point in the area. The formula [Ref. 2] used for the J/S in the program is given below.

$$\frac{J}{S} = \frac{4 \pi P_j B G_{jr} G_{rj} R_t^4 g_j^2}{P_r G_{rt}^2 \sigma R_j^2 g_t^4} \quad (7)$$

Where:

P_j = Jammer power (Watts/MHz)

B = Victim radar noise bandwidth (MHz)
 G_{jr} = Jammer antenna gain
 G_{rj} = Radar antenna gain toward jammer
 R_t = Strike group range (meters)
 g_j = Radar-to-target propagation factor
 P_r = Radar power (Watts)
 G_{rt} = Maximum radar antenna gain
 σ = Strike group cross section (square meters)
 R_j = Jammer range (meters)
 g_j = Radar-to-jammer propagation factor

All the values in this expression are readily available from stored tables or intermediate calculations with the exception of G_{rj} , the gain of the radar in the direction of the jammer platform.

Although the antenna patterns for all hostile emitters are not available, estimates of the maximum gain, beamwidth, maximum side lobe level, and average side lobe level are available from various sources. With this information it is possible to approximate an antenna aperture dimension and an Nth order cosine electric field aperture distribution [Ref. 3]. Given the aperture distribution and dimension, the side lobes in the proximity of the main lobe can be determined.

To simplify the calculations, it was assumed in the program that terminal threat radars would have uniform (zero order cosine) aperture distributions and EW/ACQ radars would

have first order cosine distributions. The half power beamwidths for each case are stored in the parameter table and can be used with wavelength to determine the aperture dimension a as given below.

THREAT RADAR:

$$a = \frac{51 \lambda}{B} \quad (8A)$$

EW/ACQ RADAR:

$$a = \frac{69 \lambda}{B} \quad (8B)$$

WHERE:

B = Half power beamwidth ($^{\circ}$)

λ = wavelength (m.)

a = Aperture dimension (m.)

Knowing a, the normalized radiation pattern for both cases can be determined from the following formulas.

THREAT RADAR:

$$E(\phi) = \frac{\text{SIN}(\psi)}{\psi} \quad (9A)$$

EW/ACQ RADARS:

$$E(\phi) = \frac{\pi}{4} \left[\frac{\sin\left(\psi + \frac{\pi}{2}\right)}{\psi + \frac{\pi}{2}} + \frac{\sin\left(\psi - \frac{\pi}{2}\right)}{\psi - \frac{\pi}{2}} \right] \quad (9B)$$

WHERE:

$$\psi = \pi \left(\frac{a}{\lambda} \right) \sin(\phi)$$

E = Far-field electric field intensity

ϕ = Azimuth

Since these expressions represent normalized patterns, they have to be multiplied by the maximum gain which is also stored in the parameter table to obtain absolute patterns. From these patterns, the program computes each side lobe level and sets the pattern equal to that level across the entire lobe to eliminate the narrow nulls. When the side lobes fall below the average side lobe level, which is a stored table value, the remainder of the pattern is set equal to this average level.

Only the maximum gain, beamwidth, average side lobe level, frequency, and EW/ACQ or terminal threat designation therefore need to be known to generate a radiation pattern approximation. Fig 8 shows an ACQ and Fig 9 a terminal threat pattern generated by this procedure. As would be expected, the ACQ radar has low side levels but it pays for this with a lower gain and wider main beam. The terminal threat radar pattern has a narrower main beam and higher gain but the side lobe levels are higher.

With the pattern information to provide an approximation

of the radar antenna gain when the actual value is unavailable, the J/S can be computed from every allowable jammer position in the operating area.

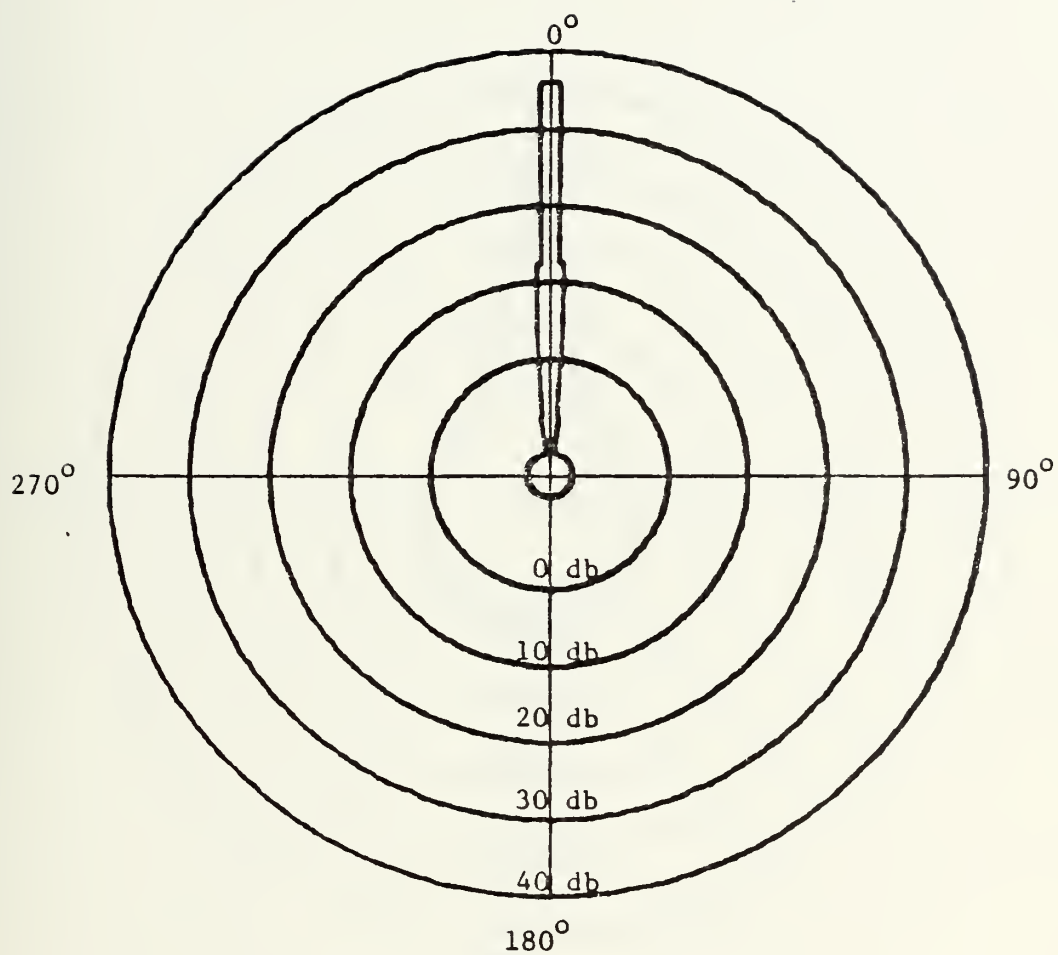


Figure 8 - APPROXIMATED ACQ RADAR PATTERN WHERE GAIN = 36 DB, BEAMWIDTH = 1.5° , AND SIDE LOBE LEVEL = -10 DB.

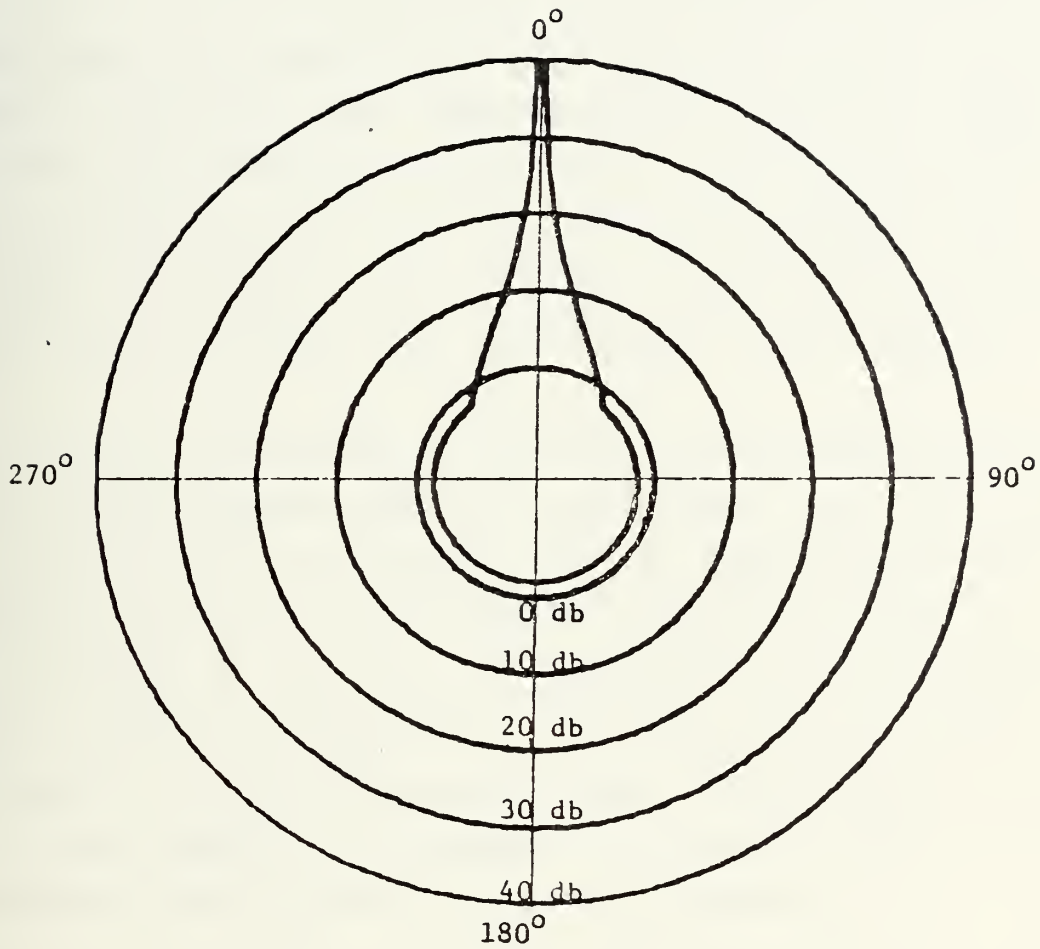


Figure 9 - APPROXIMATED THREAT RADAR PATTERN WHERE GAIN = 40 DB, BEAMWIDTH = 0.8°, AND AVERAGE SIDE LOBE LEVEL = -2 DB.

B. POWER MANAGEMENT SCHEME

An ECM aircraft is limited in the number of jammers it can carry. In a moderately dense environment there will be cases when all radars cannot be jammed. The power management scheme determines the assignments and for this program it was made very straightforward. Since a priority is computed for each radar, the available jammers are assigned on a one to one basis against the radars in descending order of priority. Therefore, the J/S is computed only against those higher priority radars for which jammers are available.

It may be possible to increase the jammer bandwidth to cover multiple signals with a single jammer but the power per MHz would be reduced and the overall effectiveness lessened. With the power management scheme utilized, if all the jammers in a band are assigned, the lower priority radars simply go uncountered. This policy makes possible the generation of a new EOB of uncoverable signals. This EOB can be run with a second aircraft of lower pucker factor through the same program to generate two mission routes without unnecessary duplication of jammer assignments.

C. OVERALL EFFECTIVENESS

The J/S varies over a wide range and can easily be as low as 10^{-6} or as high as 10^6 . Excessively high values of the J/S beyond that necessary for maximum degradation of the victim radar would be wasteful of jammer power and therefore not desired. Likewise, extremely low values of J/S would

essentially be useless against a radar and would likely waste a jammer asset which could be more useful elsewhere. The program therefore converts the J/S to db and limits it to a -25 db to +50 db range and normalizes this range. The range can be altered to reflect any desired values of minimum and maximum values for an effective J/S. The J/S figures are then multiplied by their respective priorities and jammer modulation vulnerabilities to give a weighted performance indicator for the ECM aircraft against particular radars. The modulation vulnerability is a stored table parameter associated with each emitter. It is determined experimentally and is referenced to unity being the effect of noise jamming only.

The weighted performances are then summed for all the radars that can be jammed to give a total performance factor for a particular point in the operating area. A high value for this number indicates that the high priority signals are being jammed by a high J/S with an effective jammer modulation.

D. SAMPLE EFFECTIVENESS CALCULATIONS

As an example of some of the numerical values encountered in these calculations, consider a simple static situation where there are a SAM and ACQ radar co-located at latitude $30^{\circ}30'$ and longitude $90^{\circ}30'$. If a strike aircraft with cross-section of nine square meters is located at latitude $30^{\circ}20'$ and longitude $90^{\circ}20'$, the jammer performance for a given test point latitude $30^{\circ}10'$ and longitude $90^{\circ}10'$ would be calculated as follows.

First the exposure of the ECM aircraft would have to be determined for the test point to see whether it is

acceptable. The strike group range would be 13.22 nm. and the jammer range would be 26.44 nm. Since there is only one direct threat, the SAM radar, the exposure would be calculated from equation (2) where the values of the table constants are as specified below.

$$\begin{aligned}\text{EXPOSURE} &= 1 - \left(\frac{r}{R_L} \right)^n \\ &= 1 - \left(\frac{26.44}{30.00} \right)^5 \\ &= 0.468\end{aligned}$$

Where:

$$R_L = 30.0 \text{ nm}$$

$$n = 5$$

If the maximum exposure to the ECM aircraft were 0.5, this point would be an allowable jammer position.

The next step would be to determine the priorities of each radar for the given strike position. For the ACQ radar using equation (5) the priority is determined below for the specified table constants.

$$\begin{aligned}
 \text{PRIORITY} &= P_{\max} \left[1 - \left(\frac{r}{R_{\max}} \right)^n \right] \\
 &= 0.2 \left[1 - \left(\frac{13.22}{100.0} \right)^3 \right] \\
 &= 0.1995
 \end{aligned}$$

Where:

$$\begin{aligned}
 P_{\max} &= 0.2 \\
 R_{\max} &= 100.0 \text{ nm} \\
 n &= 3
 \end{aligned}$$

The SAM priority is determined likewise from equation (6) with the range between zero and the maximum lethal range as seen below.

$$\begin{aligned}
 \text{PRIORITY} &= P'_{\max} \left[1 - \left(\frac{r}{R_L} \right)^m \right] + P_{\max} \\
 &= 0.6 \left[1 - \left(\frac{13.22}{30.00} \right)^6 \right] + 0.3 \\
 &= 0.8956
 \end{aligned}$$

Where:

$$\begin{aligned}
 P'_{\max} &= 0.6 \\
 R_L &= 30.0 \text{ nm.} \\
 m &= 6 \\
 P_{\max} &= 0.3
 \end{aligned}$$

If the ECM aircraft carries two jammers with frequency coverage such that one can cover the SAM radar while the other covers the ACQ radar, the total jamming performance can be computed for the test point. Using equation (7), the J/S can be computed for each radar as seen below for the specified radar and jammer parameters. The problem is simplified since perfect radar-strike-jammer alignment is attained at the test point. For the ACQ radar the J/S is computed as follows.

$$\begin{aligned}
 \frac{J}{S} &= \frac{4\pi P_j B G_{jr} G_{rj} R_t^4 g_j^2}{P_r G_{rt}^2 \sigma R_j^2 g_t^4} \\
 &= 105.12 \\
 &= 40.44 \text{ db.}
 \end{aligned}$$

Where:

$$\begin{aligned}
 P_j &= 200.0 \text{ W/MHz} \\
 B &= 1.0 \text{ MHz} \\
 G_{jr} &= 10.0 \text{ db}
 \end{aligned}$$

$$G_{rj} = 36.0 \text{ db}$$

$$R_t = 13.22 \text{ nm}$$

$$g_j = g_t = 1.0$$

$$P_r = 1.0 \text{ Mw}$$

$$G_{rt} = 36.0 \text{ db}$$

$$\sigma = 9.0 \text{ m}^2$$

$$R_j = 26.44 \text{ nm}$$

For the SAM radar the J/S is similarly determined.

$$\frac{J}{S} = 55.80$$

$$= 34.94 \text{ db.}$$

Where:

$$P_j = 200.0 \text{ W/MHz}$$

$$B = 0.8 \text{ MHz}$$

$$G_{jr} = 10.0 \text{ db}$$

$$G_{rj} = 40.0 \text{ db}$$

$$R_t = 13.22 \text{ nm}$$

$$g_j = g_t = 1.0$$

$$P_r = 600.0 \text{ Kw}$$

$$G_{rt} = 40.0 \text{ db}$$

$$\sigma = 9.0 \text{ m}^2$$

$$R_j = 26.44 \text{ nm}$$

These J/S values are then limited if they do not fall in the -25 db to +50 db range and then normalized. For the ACQ and SAM radars the normalized effectivenesses are adjusted as below.

$$\frac{J}{S} \text{ NORMALIZED} = \frac{\left[\frac{\left(\frac{J}{S} \right)}{50.0} \right] + 0.5}{1.5}$$

ACQ:

$$\frac{J}{S} \text{ NORMALIZED} = 0.8725$$

SAM:

$$\frac{J}{S} \text{ NORMALIZED} = 0.7992$$

If both jammers use complex modulations which have been determined to be twice as effective as Gaussian noise jamming, the J/S values are weighted by this modulation vulnerability factor of two. The J/S is also weighted by the corresponding emitter priority computed previously to give a performance indication as shown below.

$$\text{PERFORMANCE} = \left(\frac{J}{S} \right) (\text{MODULATION VULNERABILITY})(\text{PRIORITY})$$

$$\begin{aligned} \text{ACQ PERFORMANCE} &= (0.8724)(2.0)(0.1995) \\ &= 0.3481 \end{aligned}$$

$$\begin{aligned} \text{SAM PERFORMANCE} &= (0.7991)(2.0)(0.8956) \\ &= 1.4313 \end{aligned}$$

The performances against the individual radars are summed for a total performance measure for this test point.

$$\begin{aligned} \text{TOTAL PERFORMANCE} &= \text{ACQ PERFORMANCE} + \text{SAM PERFORMANCE} \\ &= 0.3481 + 1.4313 \\ &= 1.7794 \end{aligned}$$

This performance becomes the MOE for this test point. The MOE is used as a comparison between the different test points to determine the best position to designate as an ECM route point.

IV. ROUTE DETERMINATION

A. THE OPTIMUM ROUTE

The problem of determining an optimum route can most readily be determined in a case such as this through a dynamic programming approach [ref. 1]. By starting at the desired final position of the ECM aircraft, one could compute positions of high performance and by iterating back in time and retaining the optimum routes eventually come up with the optimum route which maximizes the total ECM performance. The problem encountered however is the execution time and machine size required for such a solution. For example, in a one hundred nautical mile square area in which a resolution to the nearest nautical mile in both dimensions is desired, there are ten thousand possible ECM aircraft locations. If there are thirty points in the strike route and an EOB of fifty emitters there could be fifteen million effectiveness values to be computed. Because of the flight speed constraint on the ECM aircraft, many of these results would eventually be discarded in the route determination. If the parameters of each emitter must be stored in an external device and read for each calculation, it is obvious that the time of execution will exceed that available to the aircrew.

B. ROUTE GENERATION

There are some peculiarities to the ECM route problem which allow a high performance route close to the optimum to be computed in much less time. First, the strike route will generally be planned to minimize exposure and will usually have a distinct maximum as the strike passes over the area of the target. The exposure will typically increase monotonically to this maximum and decrease in the same manner. The total priority (sum of the individual emitter priorities for a particular strike group point) will be indicative of the strike group exposure and thus reach a maximum at this same point as seen in Fig 10. Since the performance is weighted by this priority the optimum ECM route can be expected to pass through the point where performance is maximum for this particular time. This time can be determined from the priorities previously computed. All possible jammer locations for this time slot can then be checked and the ten positions of highest performance retained as possible ECM route points.

Because the total priorities decrease monotonically for strike points either side of the highest priority point, the total performances at earlier and later optimum ECM route points can be expected to decrease in the same manner since they again are weighted by the priorities. As a result, it is not necessary to look at all possible jammer locations for the next route point, only those within the one time unit ECM aircraft flight distance from the previous point. For a well defined strike exposure maximum, this is the path the optimum route would be expected to follow. This will significantly reduce the execution time and required storage space. The time unit between successive route points must be large enough so that a distinct maximum performance point can be determined but not so large as to overlook significant interim high performance points or to overfly large areas of non-allowable positions. For this program a one minute time space between route points was used.

TOTAL
PRIORITY

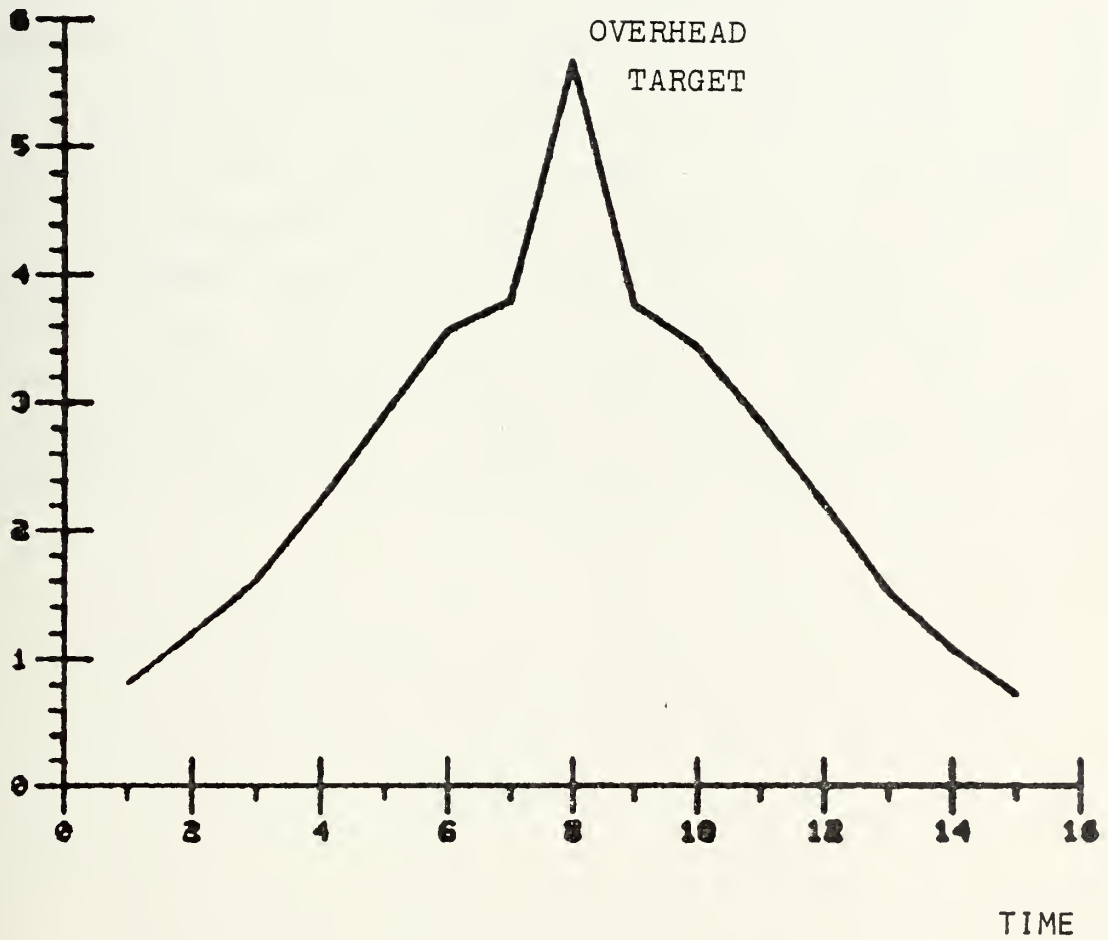


Figure 10 - STRIKE GROUP EXPOSURE (TOTAL PRIORITY AT EACH POINT) VS. TIME.

Starting with the highest strike group priority point the ECM route can be generated in two segments by iterating away from this point toward the start and finish strike group points. For each iteration, the ECM route point is determined as the highest performance point within the one minute ECM aircraft flight distance from the preceding route point as seen in Fig 11. When all these points have been calculated, the two high performance route segments to and from the optimized point are connected to form a route. The total performance at each point in the route is summed and associated with the route as its MOE. For this program, when the performance is being computed from each of the allowable jammer locations for the time of highest strike exposure, the ten points of highest performance are retained. A route is computed for each of the ten points and output with its MOE. Usually the first route will have the highest MOE but the operator has his choice of the ten.

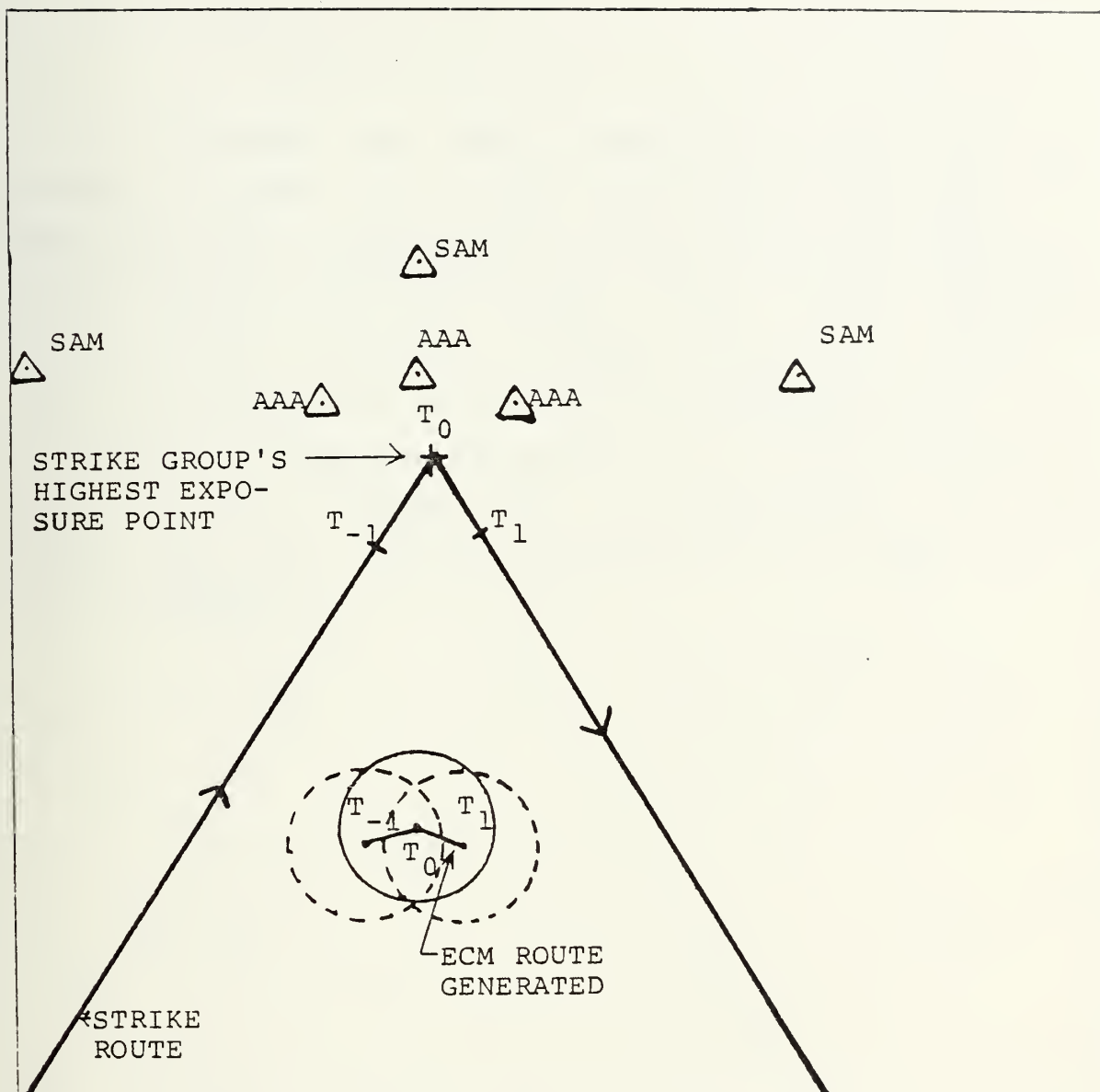


Figure 11 - ECM ROUTE GENERATION BY ITERATING FORWARD AND BACKWARD IN TIME FROM THE OPTIMUM ECM ROUTE POINT AT T_0 .

C. SAMPLE ROUTE

To illustrate the route generated by the program, consider a simple EOB of one acquisition, three SAM, and three AAA radars. The operating area will be considered a square bounded by latitude $00^{\circ} 00'$ and $01^{\circ} 30'$ and longitude $00^{\circ} 00'$ and $01^{\circ} 30'$. The strike route, threat emitter locations and maximum lethal ranges are seen in Fig 12, a blow up of the area of interest in the operating area. The ECM routes for maximum exposures of 0.0, 0.9, and 0.99 are seen in Fig 13 through Fig 15 respectively. If the exposure is set to 1.0, then as expected an escort route will be generated.

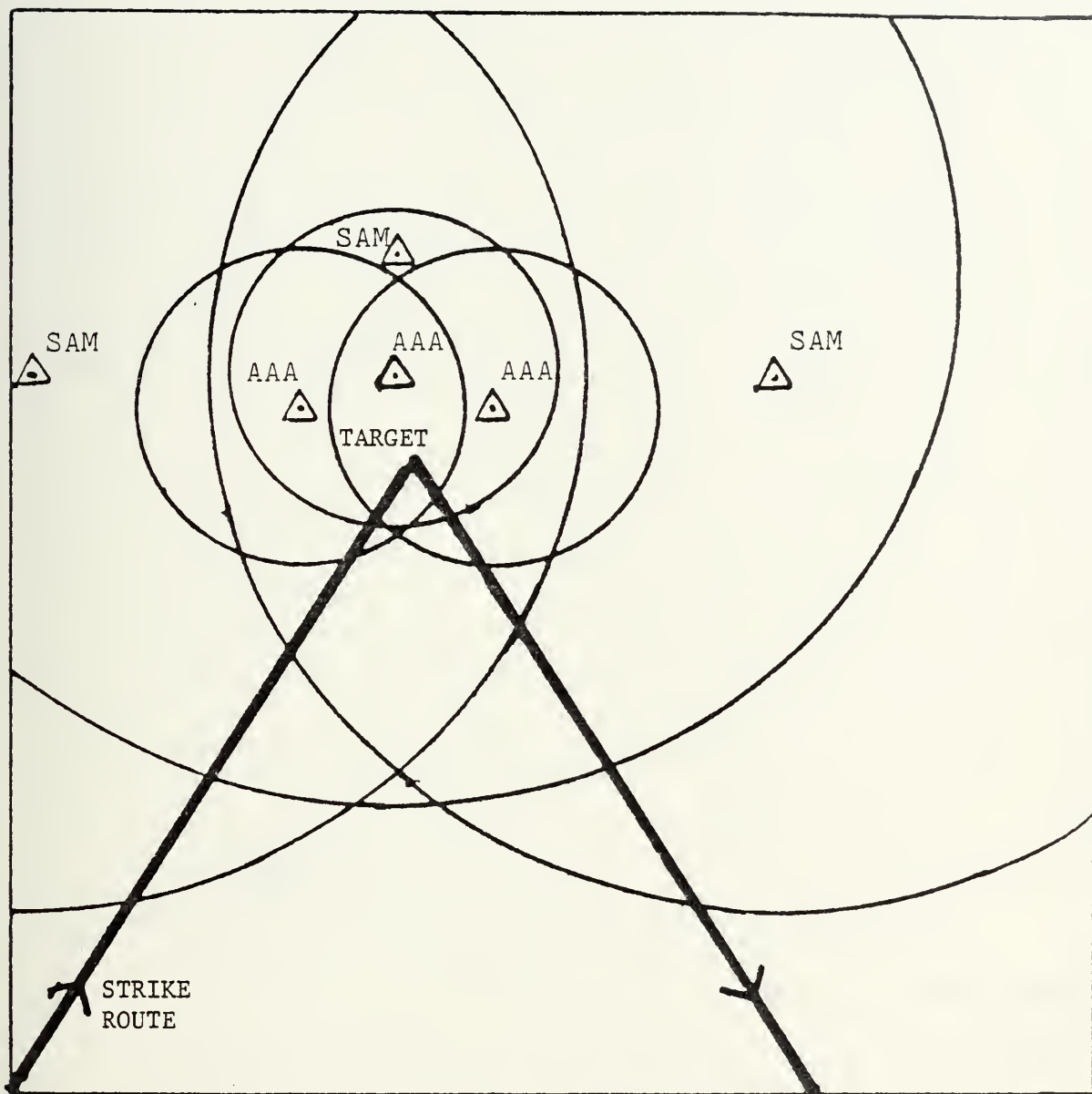


Figure 12 - SAMPLE STRIKE ROUTE AND EOB WITH MAXIMUM LETHAL RANGES OF WEAPONS ASSOCIATED WITH THE EMITTERS.

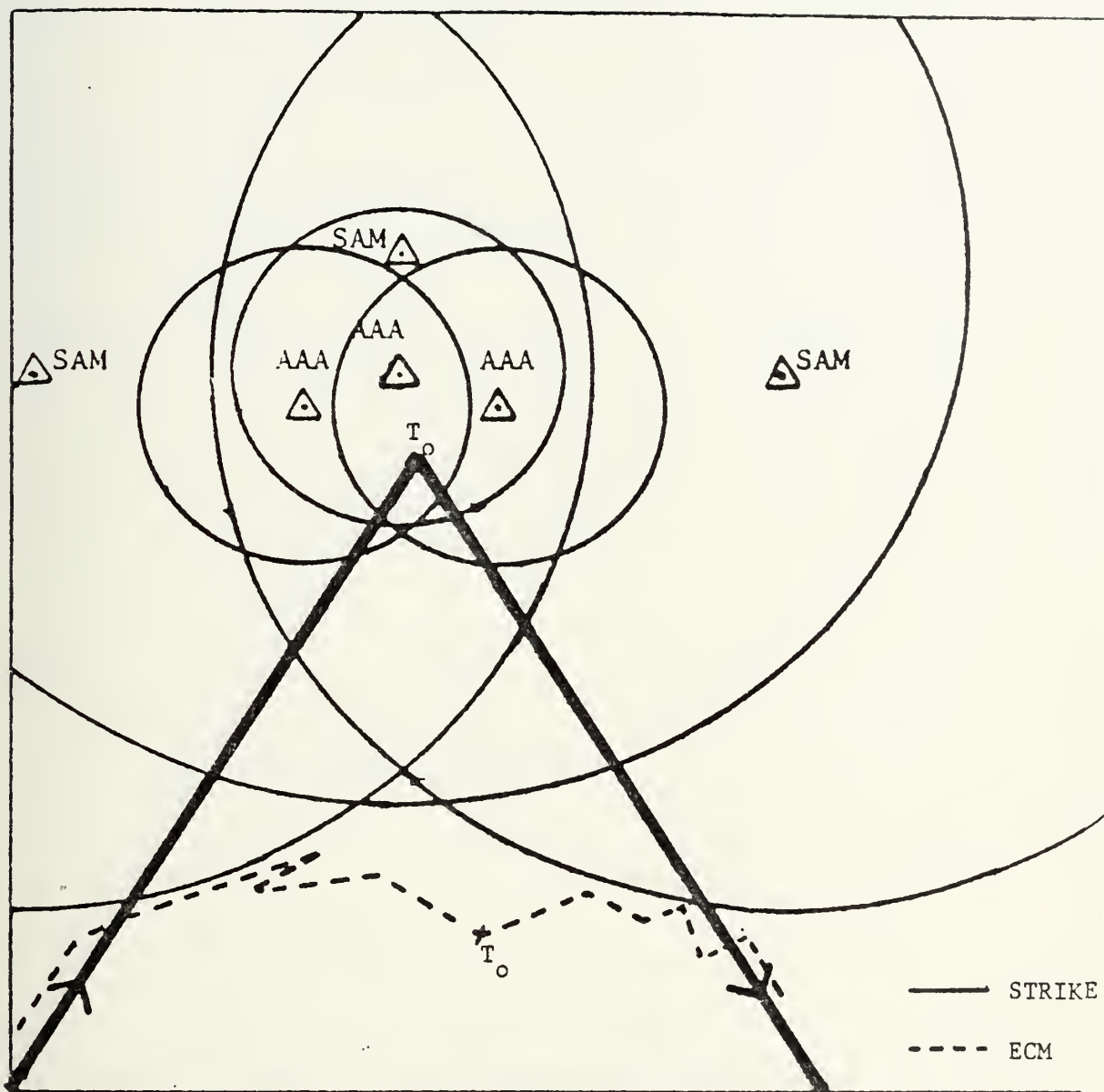


Figure 13 - ECM ROUTE GENERATED WHEN MAXIMUM EXPOSURE = 0.0.

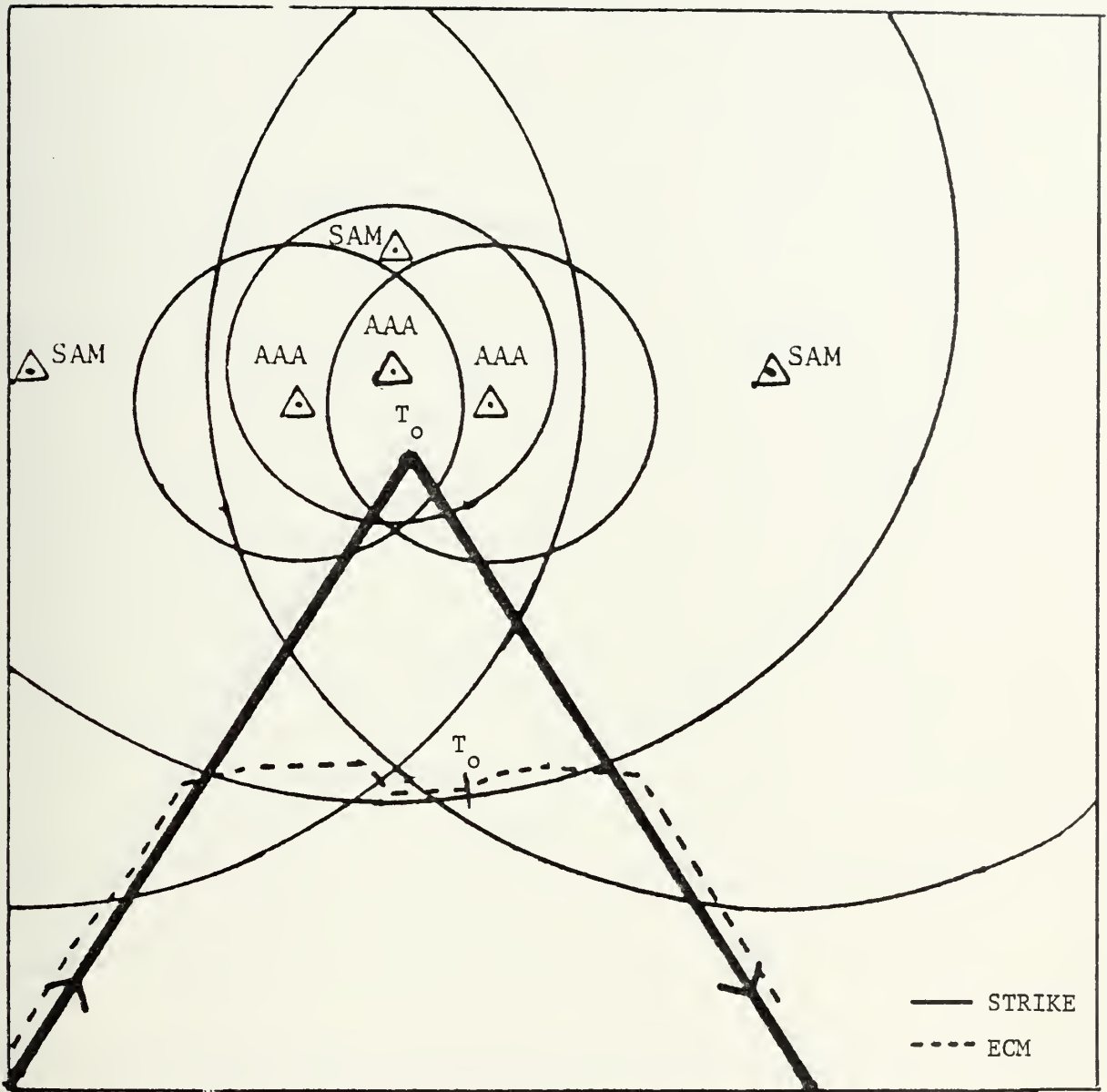


Figure 14 - ECM ROUTE GENERATED WHEN MAXIMUM EXPOSURE = 0.9.

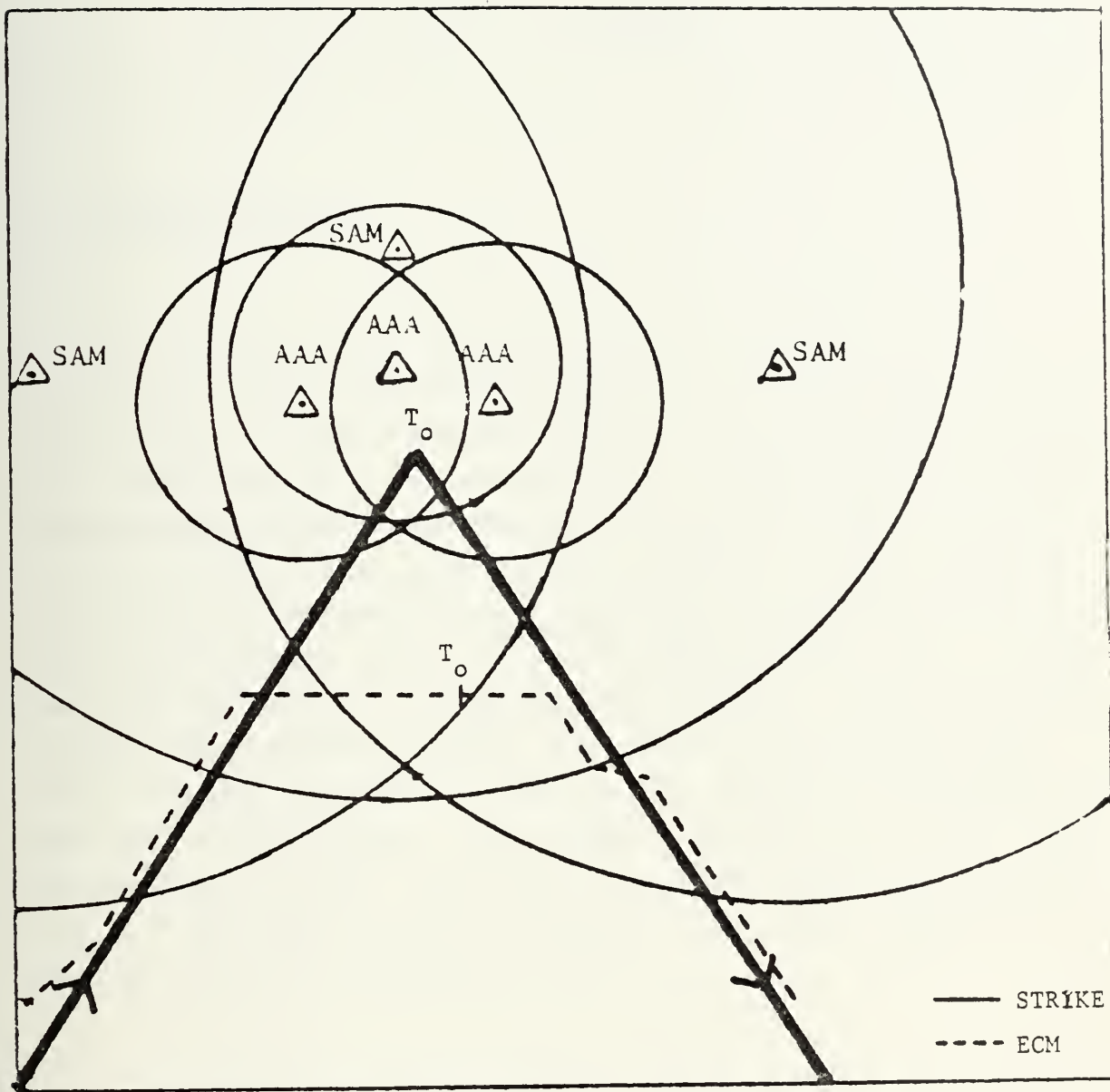


Figure 15 - ECM ROUTE GENERATED WHEN MAXIMUM EXPOSURE = 0.99.

V. SUMMARY

A. CURRENT PROGRAM

The program as presented in the preceding sections to determine a route for an ECM aircraft is very simple. In its present form it uses an excessive amount of core storage but only because of the intermediate testing done during its development. In translating to a smaller machine it can be readily compacted to significantly reduce the size required. It must be remembered that the route generated is not the absolute optimum, but a one point optimization with a high performance route to and from this point. For the typical strike route and EOB though, the route should come close to the absolute optimum. The program listing is enclosed at the end of this report. The program was run on the Naval Postgraduate School IBM-360/67 computer under CP/CMS System and for the sample routes generated it took approximately twelve minutes of computer time.

B. SUGGESTIONS FOR IMPROVEMENT

If external storage such as floppy disk is available on the system which incorporates this program, there are several areas where the program performance could be enhanced without a significant increase in size or execution time. The antenna patterns could be pre-computed for all hostile emitters and stored in an external table for simple

lookup of the value needed. If this is done the aperture can be better approximated and a more accurate pattern can be computed since the computation time would not be a factor. The J/S could be weighted by an additional factor indicative of experimental results of jammer effectiveness measurements against known system types. This factor would also be predetermined for each hostile emitter and stored externally as a function of jammer range. In computing the allowable positions for the ECM aircraft within the maximum exposure limits, the computed exposure can be modified to reflect the reduced exposure to the ECM aircraft due to its own jamming. The jamming performance can also be adjusted to indicate increased performance when jammer frequencies and pointing angles overlap. This would possibly require a different jammer management scheme. It would also be easy to observe the total priority as a function of strike group position to determine how it increases to its highest point and then falls off. This characteristic could then be translated to indicate to the operator how far from the optimum the generated route deviates. The final program should be checked with a complete dynamic programming optimization to determine when it becomes unreliable as a planning tool.


```

C C C C C
PROGRAM TO DETERMINE AN OPTIMUM ECM ROUTE FOR A
JAMMER AIRCRAFT IN SUPPORT OF A GIVEN STRIKE ROUTE
MAN00010
MAN00020
MAN00030
MAN00040
MAN00050
MAN00060
MAN00070
MAN00080
MAN00090
MAN00100
MAN00110
MAN00120
MAN00130
MAN00140
MAN00150
MAN00160
MAN00170
MAN00180
MAN00190
MAN00200
MAN00210
MAN00220
MAN00230
MAN00240
MAN00250
MAN00260
MAN00270
MAN00280
MAN00290
MAN00300
MAN00310
MAN00320
MAN00330
MAN00340
MAN00350
MAN00360
MAN00370
MAN00380
MAN00390
MAN00400
MAN00410
MAN00420
MAN00430
MAN00440
MAN00450
MAN00460
MAN00470
MAN00480

DIMENSION SLAT(50),SLON(50),SLAT1(50),SLON1(50),SLAT2(50),SLON2(50),NPRTY(50),
1) ,RLNT1(50),ELNT2(50),JXN(20),F1(10),F2(10),PWR(10),GAN(10),IMITE(50),
2) ,ELNT1(50),GN(180),G(50,180),TOTP(10),ELAT1(50,10),ELCN1(50,10),
3) CO(100),TPRTY(50),ELAT2(50,10),ELON2(50,10),R1FACT(10),R2FACT(10),LT1(10),
4) (50,10),RADN1(50),RADN2(50),RMAX(50),RL(50),PMAX(50),PPMAX(50),FM(50),
5) LN1(10),FREQ(50),RPWR(50),GMAX(50),BEAM(50),AVGSLL(50),ITRAK(50),
6) ,FMOD(50)
7) ,INTEGER RADN1,RADN2,ELNT1,ELNT2
INPUT THE GEOGRAPHICAL LIMITS OF THE OPERATING AREA BY LAT/LON
REAC(3,0100)ALAT,ALON,BLAT,BLON
FCRMAT(4F10.2)

0100
C C C C C
INPUT THE NUMBER OF STRIKE ROUTE POINTS(ISTK) AND RADAR CROSS
SECTION(CRSCT)
READ(3,0110)ISTK,CRSCT
FCRMAT(13,F10.2)

0110
C C C C C
INPUT THE STRIKE ROUTE AS POINTS SEPARATED BY ONE MINUTE IN TIME
BY LAT/LON(SLAT,SLON)
REAC(3,0120)(SLAT(I),SLON(I),I=1,ISTK)
FCRMAT(2F10.2)

0120
C C C C C
INPUT THE NUMBER OF RADARS IN THE AREA EOB (NTOT) AND THE TOTAL
NUMBER OF ENTRIES IN THE ELINT PARAMETER TABLE(NTAB)
READ(5,0130)NTOT,NTAB
FCRMAT(2I3)

0130
C C C C C
INPUT THE AREA EOB BY ELINT NUMBER(ELNT1,ELNT2) AND LAT/LON(RLAT,
RLCN)
READ(4,0140)(ELNT1(I),ELNT2(I),RLAT(I),RLCN(I),I=1,NTCT)
FCRMAT(2A4,2F10.2)

0140
C C C C C
INPUT THE PUCKER FACTOR(PUKR) NUMBER OF JAMMERS(NJAM) AND THE
MAXIMUM ONE MINUTE FLIGHT DISTANCE FOR THE ECM AIRCRAFT
REAC(5,0150)PUKR,NJAM,DMAX

```



```

I=LAI-M
J=LCI-N
IMITE(K,L)=IMITE(I,J)
CCNTINUE
NCW FRAME IMITE IN -1'S (ALLOWS NO FLIGHTS CUT OF AREA)
DC 0240 IN=1,LA2
IMITE(IN,1)=-1
IMITE(IN,LO2)=-1
CCNTINUE
DC 0250 IN=1,LO2
IMITE(1,IN)=-1
IMITE(LA2,IN)=-1
CCNTINUE
NCW SWEEP REPEATEDLY ACROSS IMITE SETTING ACCESSIBLE 0'S TO 1
NCC=2*LAI
DC 0260 NSWEP=1,NUD
DC 0260 M=2,LAI
DC 0260 N=2,LO1
LCCATE THE START POINT OR EVENTUAL ACCESSIBLE POINTS
IF(IMITE(M,N).NE.1)GO TO 0260
IF(CHANGE EVERY ACCESSIBLE ZERO FROM THIS POINT TO 1
IF(IMITE(M,N-1).EQ.0)IMITE(M,N-1)=1
IF(IMITE(M+1,N-1).EQ.0)IMITE(M+1,N)=1
IF(IMITE(M+1,N+1).EQ.0)IMITE(M+1,N+1)=1
IF(IMITE(M,N+1).EQ.0)IMITE(M,N+1)=1
IF(IMITE(M,N+1).EQ.0)IMITE(M,N+1)=1
IF(IMITE(M-1,N+1).EQ.0)IMITE(M-1,N+1)=1
IF(IMITE(M-1,N-1).EQ.0)IMITE(M-1,N)=1
IF(IMITE(M-1,N-1).EQ.0)IMITE(M-1,N-1)=1
CCNTINUE
REMOVE THE FRAME AND SHIFT IMITE ONE UNIT DCWN IN LAT/LON
DC 0270 M=1,LAT
DC 0270 N=1,LCN
IMITE(M,N)=IMITE(M+1,N+1)
CCNTINUE
DETERMINE THE STRIKE ROUTE POINT OF HIGHEST TOTAL PRIORITY. THIS
PCINT WILL BE A MUST POINT LATER FOR HIGHEST JAMMING EFFECTIVENESS
ITERATE FOR EACH STRIKE GROUP POINT
PTEMP=0
DC 0350 I=1,ISTK
IFRTY(I)=0
ITERATE FOR EACH RADAR IN THE EOB
DC 0340 J=1,NTOT
SEARCH THE PARAMETER TABLE FOR THIS RADAR
DC 0330 K=1,NTAB
IF((RADN1(K).EQ.ELNT1(J)).AND.(RACN2(K).EQ.ELNT2(J)))GO TO 0331

```



```

033J CCNTINUE
033I CCNTINUE
C DETERMINE THE RANGE FROM THIS RADAR TO THE STRIKE
C R=RANJ(SLAT(I),SLON(I),RLAT(J),RLCN(J))
C BASED ON THIS RANGE ASSIGN THE PROPER PRIORITY TO THE RADAR
C IF(R.LE.RL(K))PRTY(I,J)=PPMAX(K)*(1.-(R/RL(K))*FM(K))+PMAX(K)
C IF((R.GT.RL(K)).AND.(R.LE.RMAX(K)))PRTY(I,J)=PMAX(K)*(1.-(R/RMAX(K)
1)))*FN(K))
C IF(R.GT.RMAX(K))PRTY(I,J)=0.
C DETERMINE THE TOTAL PRIORITY(TPRTY) AT THIS STRIKE POSITION
C TPRTY(I)=TPRTY(I)+PRTY(I,J)
C CCNTINUE
0340 C OUTPUT THE TOTAL PRIORITY FOR EACH STRIKE GROUP POSITION TO
C CBLERVE HOW IT FALLS OFF FROM MAXIMUM EXPOSURE POINT.
C THIS RCLL-OFF WILL INDICATE HOW CLOSE THE RCUTE TO BE
C GENERATED WILL COME TO AN ABSOLUTE OPTIMUM ROUTE.
C WRITE(6,3341)TPRTY(I)
C FCRMAT(20X,E16.8)
0341 C RETAIN THE HIGHEST PRIORITY STRIKE POINT(IMAX)
C IF(TPRTY(I).LE.PTEMP)GO TO 0350
C PTEMP=TPRTY(I)
C IMAX=I
C CCNTINUE
0350 C
C
C
C DIVIDE THE STRIKE ROUTE INTO TWO SECTIONS ABOUT THE HIGHEST
C PRIORITY POINT(IMAX)
C ISTK1=IMAX
C ISTK2=ISTK-IMAX+1
C DO C400 I=1,ISTK1
C J=IMAX+1-I
C SLAT1(I)=SLAT(J)
C SLCN1(I)=SLCN(J)
C DO C400 KK=1,NTOT
C PRTY1(I,KK)=PRTY(J,KK)
C CCNTINUE
C DO C410 I=1,ISTK2
C J=IMAX-1+I
C SLAT2(I)=SLAT(J)
C SLCN2(I)=SLCN(J)
C DO C410 KK=1,NTOT
C PRTY2(I,KK)=PRTY(J,KK)
C CCNTINUE
0400 C
C
C
C DETERMINE THE ANTENNA PATTERNS FOR THE RADARS
C DC C440 I=1,NTOT
C SEARCH THE PARAMETER TABLE FOR THIS RADAR
C DC 0430 J=1,NTAB

```

MAN01930
MAN01940
MAN01950
MAN01960
MAN01970
MAN01980
MAN01990
MAN02000
MAN02010
MAN02020
MAN02030
MAN02040
MAN02050
MAN02060
MAN02070
MAN02080
MAN02090
MAN02100
MAN02110
MAN02120
MAN02130
MAN02140
MAN02150
MAN02160
MAN02170
MAN02180
MAN02190
MAN02200
MAN02210
MAN02220
MAN02230
MAN02240
MAN02250
MAN02260
MAN02270
MAN02280
MAN02290
MAN02300
MAN02310
MAN02320
MAN02330
MAN02340
MAN02350
MAN02360
MAN02370
MAN02380
MAN02390
MAN02400

0430	IF((RADN1(J).EQ.ELNT1(I)).AND.(RACN2(J).EQ.ELNT2(I)))GO TO 0431	MAN02410
0431	CCNTINUE	MAN02420
	CALL ANTOB(GMAX(J),BEAM(J),AVGSLL(J),FREQ(J),ITRAK(J),GN)	MAN02430
	DC 0435 KL=1,180	MAN02440
	G(I,KL)=GN(KL)	MAN02450
0435	CCNTINUE	MAN02460
0440	CCNTINUE	MAN02470
	DC 0461 KL=1,10	MAN02480
	LT1(KL)=0	MAN02490
	LN1(KL)=0	MAN02500
	TCTP(KL)=0.	MAN02510
0461	CCNTINUE	MAN02520
C	CHANGE ALL MAXIMUM ANTENNA GAIN VALUES FROM DB TO LINEAR	MAN02530
	DC 0462 I=1,NTAB	MAN02540
	GMAX(I)=10.**((GMAX(I)/10.))	MAN02550
0462	CCNTINUE	MAN02560
C		MAN02570
C	DETERMINE THE ORDER OF PRIORITY	MAN02580
	CALL ORDER(PRTY,NTOT,NPRTY,IMAX)	MAN02590
		MAN02600
C		MAN02610
C	DETERMINE THE TEN BEST LOCATIONS FOR THE JAMMER AT THE STRIKE	MAN02620
C	GROUP'S HIGHEST PRIORITY POINT	MAN02630
C	ITERATE FOR ALLOWABLE OPERATING POINTS	MAN02640
	DO 0490 M=1,LAT	MAN02650
	DC 0490 N=1,LCN	MAN02660
	IF(IMIT(M,N).NE.1)GO TO 0490	MAN02670
C	ADJUST THIS POINT TO THE OPERATING AREA DISTANCE SCALE	MAN02680
	PLAT=M	MAN02690
	PLCN=N*SKAL	MAN02700
		MAN02710
C	INITIALIZE THE TOTAL EFFECTIVENESS VALUE(TEFF) TO RERC	MAN02720
	TEFF=0.	MAN02730
C	ITERATE FOR RADARS IN DESCENDING ORDER OF PRIORITY	MAN02740
	DC 0485 I=1,NTOT	MAN02750
	DC 0465 J=1,NTAB	MAN02760
	IF((RADN1(J).EQ.ELNT1(NPRTY(I)).AND.(RADN2(J).EQ.ELNT2(NPRTY(I)))	MAN02770
	1)GC TO 0466	MAN02780
0465	CCNTINUE	MAN02790
0466	CCNTINUE	MAN02800
C	CHECK TO SEE IF A JAMMER IS AVAILABLE	MAN02810
	DC 0470 K=1,NJAM	MAN02820
	IF((FREQ(J).LT.F1(K)).OR.(FREQ(J).GT.F2(K))) GO TO 0470	MAN02830
	IF(JXN(K).EQ.0)GO TO 0470	MAN02840
	JXN(K)=0	MAN02850
C	JAMMER K IS AVAILABLE	MAN02860
	GC TO 0472	MAN02870
		MAN02880

0470	CCNTINUE	MAN02890
C	NC JAMMER IS AVAILABLE GO TO NEXT RADAR	MAN02900
	GC TO 0485	MAN02910
0472	CCNTINUE	MAN02920
C	CCMPUTE THE J/S	MAN02930
C	FIRST COMPUTE THE RADAR- STRIKE(RSTK) AND RADAR-JAMMER(RJX) RANGES	MAN02940
	RSTK=1852.*RANJ(RLAT(NPRTY(I)),RLCN(NPRTY(I)),SLAT(IMAX),SLON(IMAX	MAN02950
	1))	MAN02960
	RJX=1852.*RANJ(RLAT(NPRTY(I)),RLCN(NPRTY(I)),PLAT,PLCN)	MAN02970
C	SET THE MINIMUM RANGE TO ONE NAUTICAL MILE. THIS WILL PREVENT	MAN02980
C	THE J/S FROM GOING TO INFINITY FOR JAMMER PCSITIONS OVERHEAD	MAN02990
C	A RADAR SITE	MAN03000
	IF(RSTK.LT.1852.)RSTK=1852.	MAN03010
	IF(RJX.LT.1852.)RJX=1852.	MAN03020
C	MEASURE THE STRIKE-RADAR-JAMMER ANGLE (THETA)	MAN03030
	THETA=ABS((ATAN2(RLAT(NPRTY(I))-SLON(IMAX),RLAT(NPRTY(I))-SLAT(IMAX	MAN03040
	1X)))-(ATAN2(RLAT(NPRTY(I))-PLON,RLAT(NPRTY(I))-PLAT))*57.29577951	MAN03050
	IF(THETA.GT.180.)THETA=360.-THETA	MAN03060
	IFTHETA=THETA+1.	MAN03070
C	CCMPUTE THE J/S (EFFECT)	MAN03080
	EFFECT=((49*3.141592654*PWR(K)*(10.**((GAN(K)/10.))*G(NPRTY(I),ITHETA	MAN03090
	1))*RSTK**4)/(RPWR(J)*GMAX(J)**2*CRSCT*RJX**2))	MAN03100
C	CCNVERT THE J/S TO DB AND LIMIT IT TO A RANGE OF -25DB TO +50CB	MAN03110
C	ACRMLIZE THIS RANGE ZERO TO ONE	MAN03120
	EFFECT=((20.*ALOG10(EFFECT))/50.+5)/1.5	MAN03130
	IF(EFFECT.GT.1.)EFFECT=1.	MAN03140
	IF(EFFECT.LT.0.)EFFECT=0.	MAN03150
C	WEIGHT THE J/S BY THE PRIORITY AND THE MODULATION VULNERABILITY	MAN03160
C	(FMCD) OF THE ASSOCIATED RADAR	MAN03170
	PERF=EFFECT*PRTY(IMAX,NPRTY(I))*FMCD(J)	MAN03180
C	SLM THE PERFORMANCES AGAINST THE INDIVIDUAL RADARS FGR A TOTAL	MAN03190
C	PERFORMANCE (TEFF) INDICATION FROM THIS JAMMER LOCATION	MAN03200
	TEFF=TEFF+PERF	MAN03210
0485	CCNTINUE	MAN03220
C	RETAIN THE TEN BEST PERFORMANCE POINTS	MAN03230
	CALL GDPTS(M,N,TEFF,LT1,LT1,TOTP)	MAN03240
C	RESET THE JAMMER AVAILABILITY	MAN03250
	DC 0490 JI=1,NJAM	MAN03260
	JXN(JI)=1	MAN03270
0490	CCNTINUE	MAN03280
C	OUTPUT THE TEN BEST LOCATIONS FOR THE JAMMER FOR THE STRIKE GROUP	MAN03290
C	HIGHEST EXPOSURE POINT	MAN03300
	WRITE(6,0471)(LT1(I),TOTP(I),I=1,10)	MAN03310
	FCRMAT(215,E16.8)	MAN03320
0471		MAN03330
C		MAN03340
C	SET THE INITIAL ECM ROUTE POINTS TO THE BEST POINTS AT IMAX	MAN03350
	DC 0600 I=1,10	MAN03360


```

060C  ELAT1(1,I)=LT1(I)
C      ELAT2(1,I)=LT1(I)
C      ELCN1(1,I)=LN1(I)
C      ELCN2(1,I)=LN1(I)
C      CCNTINUE
C      ITERATE FOR THE TEN IMAX POINTS
C      DC C80J I=1,10
C      R1FACT(I)=0.
C      R2FACT(I)=0.
C      ITERATE FOR ROUTE SEGMENT ONE
C      ISI=ISTK1-1
C      IF(IS1.EQ.0)GO TO 0650
C      DC C650 J=1,ISI
C      CALL ORDER(PRTY1,NTOT,NPRTY,J)
C      ITERATE FOR THE POINTS IN THE OPERATING AREA
C      TLAST=0.
C      DC C640 M=1,LAT
C      DC C64J N=1,LON
C      T-RCW OUT POINTS THAT ARE NOT ALLCWD OR TOC FAR FROM PREVIOUS PT
C      PLAT=M
C      PLCN=N*SKAL
C      IF((IMITE(M,N).NE.1).OR.(RANJ(PLAT,PLON,ELAT1(J,I),ELON1(J,I))*SKAL
1)  .GT.DMAX))GO TO 0640
C      TEFF=0.
C      ITERATE FOR RADARS IN THE EOB IN DESCENDING ORDER CF PRIORITY
C      CC C630 K=1,NTOT
C      SEARCH THE PARAMETER TABLE
C      DC C605 II=1,NTAB
C      IF((RADN1(II).EQ.ELNT1(NPRTY(K)).AND.(RADN2(II).EQ.ELNT2(NPRTY(K)
1)  )) GO TO 0606
C      CCNTINUE
C      CCNTINUE
C      CHECK TO SEE IF A JAMMER IS AVAILABLE
C      DC C620 L=1,NJAM
C      IF((FREQ(II).LT.F1(L)).OR.(FREQ(II).GT.F2(L)))GO TO 0620
C      IF(JXN(L).EQ.0)GO TO 0620
C      JXN(L)=0.
C      JAMMER L IS AVAILABLE
C      CC TO 0621
C      CCNTINUE
C      NC JAMMER IS AVAILABLE, GO TO NEXT LOWER PRIORITY RADAR
C      CC TO 0630
C      CCNTINUE
C      CCNTINUE THE J/S
C      CCMPUTE THE J/S
C      FIRST MEASURE THE DISTANCE FROM THE RADAR TC THE STRIKE AND JAMMER
C      RSTK=1852.*RANJ(RLAT(NPRTY(K)),RLCN(NPRTY(K)),SLAT1(J+1),SLON1(J
1+1))
MAN03370
MAN03380
MAN03390
MAN03400
MAN03410
MAN03420
MAN03430
MAN03440
MAN03450
MAN03460
MAN03470
MAN03480
MAN03490
MAN03500
MAN03510
MAN03520
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MAN03600
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MAN03700
MAN03710
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MAN03740
MAN03750
MAN03760
MAN03770
MAN03780
MAN03790
MAN03800
MAN03810
MAN03820
MAN03830
MAN03840

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```

C      RJX=1852.*RANJ(RLAT(NPRTY(K)),RLCN(NPRTY(K)),PLAT,PLCN)
C      LIMIT THE RANGES TO ONE NAUTICAL MILE. THIS KEEPS THE J/S FROM
C      GOING TO INFINITY FOR JAMMER LOCATIONS OVERHEAD A RADAR.
C      IF(RSTK.LT.1852.)RSTK=1852.
C      MEASURE THE STRIKE-RADAR--JAMMER ANGLE
C      THETA=ABS((ATAN2(RLON(NPRTY(K))-SLON1(J+1),RLAT(NPRTY(K))-SLAT1(J+MAN03900
11)))-(ATAN2(RLON(NPRTY(K))-PLON,RLAT(NPRTY(K))-PLAT)))*57.29577951
C      IF(THETA.GT.180.)THETA=360.-THETA
C      COMPUTE THE J/S (EFFECT)
C      EFFECT=((4.*3.141592654*PWR(L)*(10.**((GAN(L)/10.))*G(NPRTY(K),THETA+
11)*RSTK**4)/(RPWR(II)*GMAX(II)**2*CRSCT*RJX**2))
C      CONVERT THE J/S TO DB AND LIMIT IT TO A RANGE OF -25DB TO +50DB
C      NCRMALIZE THIS RANGE ZERO TO ONE
C      EFFECT=((20.*ALOG10(EFFECT))/50.+5)/1.5
C      IF(EFFECT.GT.1.)EFFECT=1.
C      IF(EFFECT.LT.C.)EFFECT=0.
C      WEIGHT THE J/S BY THE PRIORITY AND MODULATION VULNERABILITY
C      PERF=EFFECT*PRTY1(J+1,NPRTY(K))*FMC0(II)
C      SUM THE PERFORMANCES AGAINST THE INDIVIDUAL RADARS FOR A TOTAL
C      PERFORMANCE INDICATOR FROM THIS JAMMER LOCATION
C      TEFF=TEFF+PERF
063C  CCNTINUE
C      RETAIN THE BEST POINT AS AN ECM ROUTE POINT
C      IF(TEFF.LT.TLAST)GO TO 0635
C      TLAST=TEFF
C      ELCTN1(J+1,I)=M
C      RESET THE JAMMER AVAILABILITY
0635  DC 0640 JN=1,NJAM
C      JXN(JN)=1
C      CCNTINUE
C      RIFACT(I)=RIFACT(I)+TLAST
0640  CCNTINUE
C      ITERATE FOR ROUTE SEGMENT TWO
C      IS2=ISTK2-1
C      IF(IS2.EQ.0)GO TO 0750
C      DC C 0750 J=1,IS2
C      CALL ORDER(PRTY2,NTOT,NPRTY,J)
C      ITERATE FOR POINTS IN THE OPERATING AREA
C      TLAST=0.
C      DC 0740 M=1,LAT
C      DC 0740 N=1,LCN
C      THROW OUT THE POINTS THAT ARE NOT ALLOWED OR TOO FAR FROM PREVIOUS
C      PLAT=M*SKAL
C      PLCN=N*SKAL
C      IF((IMITE(M,N).NE.1).OR.((RANJ(PLAT,PLON,ELAT2(J,I),ELON2(J,I))*SKAL
1).GT.DMAX))GO TO 0740

```



```

C      TEFF=0.      FOR THE RACARS IN THE OPERATING AREA
C      ITERATE K=1,NTOT
C      CC 0730 K=1,NTOT
C      SEARCH THE PARAMETER TABLE
C      DC 0705 II=1,NTAB
C      IF ((RADN1(II)).EQ.ELNT1(NPRTY(K))).AND.(RADN2(II).EQ.ELNT2(NPRTY(K)
1))) GO TO 0706
C      CCNTINUE
C      CCNTINUE
C      CFECK TO SEE IF A JAMMER IS AVAILABLE
C      DC C720 L=1,NJAM
C      IF ((FREQ(II)).LT.F1(L)).OR.(FREQ(II).GT.F2(L)) GO TO 0720
C      IF (JXN(L).EC.0) GO TO 0720
C      JXN(L)=0
C      JAMMER L IS AVAILABLE
C      GC TO 0721
C      CCNTINUE
C      NC JAMMER AVAILABLE
C      GC TO 0730
C      CCNTINUE
C      COMPUTE THE J/S
C      FIRST MEASURE THE RANGE FROM THE RADAR TTC THE STRIKE
C      AND JAMMER
C      RSTK=1852.*RANJ(RLAT(NPRTY(K)),RLCN(NPRTY(K)),SLAT2(J+1),SLON2(J+1)
1))
C      RJX=1852.*RANJ(RLAT(NPRTY(K)),RLON(NPRTY(K)),PLAT,PLCN)
C      LIMIT THE MINIMUM RANGE TO ONE NAUTICAL MILE. THIS WILL KEEP
C      THE J/S FROM GOING TO INFINITY FOR JAMMER LCCATIONS CVERHEAD A
C      RADAR SITE
C      IF (RSTK.LT.1852.) RSTK=1852.
C      IF (RJX.LT.1852.) RJX=1852.
C      MEASURE THE STRIKE-RADAR-JAMMER ANGLE
C      THE TA=ABS((ATAN2(RLON(NPRTY(K))-SLON2(J+1),RLAT(NPRTY(K))-SLAT2(J+1)
1)))-(ATAN2(RLON(NPRTY(K))-PLON,RLAT(NPRTY(K))-PLAT))*57.29577951
C      IF (THE TA.GT.180.) THE TA=360.-THE TA
C      COMPUTE THE J/S
C      EFCT=((4.*3.141592654*PWR(L)*(10.**((GAN(L)/10.))*G(NPRTY(K),THETA+
1))*RSTK**4)/(RPWR(II)*GMAX(II)**2*CRSCT*RJX**2))
C      CCNVERT THE J/S TO DB AND LIMIT IT TO A RANGE OF -25DB TO +50CB
C      NCRMALIZE THIS RANGE ZERO TO ONE
C      EFCT=((20.*ALOG10(EFCT))/50.+5)/1.5
C      IF (EFCT.GT.1.) EFCT=1.
C      IF (EFCT.LT.0.) EFCT=J.
C      WEIGHT THE J/S BY THE PRIORITY AND MODULATION VULNERABILITY
C      PERFF=EFCT*PRTY2(J+1,NPRTY(K))*FMCC(II)
C      SUM THE INDIVIDUAL PERFCRMANCES FOR A TOTAL PERFORMANCE INDICATOR
C      FRCM THIS JAMMER LOCATION
C      TEFF=TEFF+PERF

```

MAN04330
 MAN04340
 MAN04350
 MAN04360
 MAN04370
 MAN04380
 MAN04390
 MAN04400
 MAN04410
 MAN04420
 MAN04430
 MAN04440
 MAN04450
 MAN04460
 MAN04470
 MAN04480
 MAN04490
 MAN04500
 MAN04510
 MAN04520
 MAN04530
 MAN04540
 MAN04550
 MAN04560
 MAN04570
 MAN04580
 MAN04590
 MAN04600
 MAN04610
 MAN04620
 MAN04630
 MAN04640
 MAN04650
 MAN04660
 MAN04670
 MAN04680
 MAN04690
 MAN04700
 MAN04710
 MAN04720
 MAN04730
 MAN04740
 MAN04750
 MAN04760
 MAN04770
 MAN04780
 MAN04790
 MAN04800


```

0730 CCNTINUE THE BEST PCINT AS AN ECM RCUTE POINT
C IF(TEFF.LT.TLAST)GO TO 0735
TLAST=TEFF
ELAT2(J+1,I)=M
ELCN2(J+1,I)=N
RESET THE JAMMER AVAILABILITY
CC 0740 JN=1,NJAM
JXN(JN)=1
CCNTINUE
R2FACT(I)=R2FACT(I)+TLAST
CCNTINUE
TOTP(I)=TOTP(I)+R1FACT(I)+R2FACT(I)
CCNTINUE
SHIFT THE 0/0 REFERENCED AREA USED DURING CALCULATIONS BACK
TO ITS INITIAL LAT/LON. OUTPUT THE ROUTE NUMBER, MEASURE OF
EFFECTIVENESS, AND ROUTE POINTS.
CC 0900 I=1,10
WRITE(6,0805)I,TOTP(I)
FCRMAT(/,2X,I3,5X,E16.8)
CC 0850 J=1,ISTK1
AA=(DGMN(ALAT)+ELAT1(J,I)+.1)/60.
BB=(DGMN(ALCN)+ELON1(J,I)+.1)/60.
ELAT1(J,I)=(AA-INT(AA))*0.6+INT(AA)
ELCN1(J,I)=(BB-INT(BB))*0.6+INT(BB)
CCNTINUE
CC 0870 J=1,ISTK2
CC=(DGMN(ALAT)+ELAT2(J,I)+.1)/60.
CC=(DGMN(ALCN)+ELON2(J,I)+.1)/60.
ELAT2(J,I)=(CC-INT(CC))*0.6+INT(CC)
ELCN2(J,I)=(DD-INT(DD))*0.6+INT(DD)
CCNTINUE
CC 0890 KK=1,ISTK1
K=ISTK1-KK+1
WRITE(6,0875)ELAT1(K,I),ELON1(K,I)
FCRMAT(10X,F10.2,5X,F10.2)
CCNTINUE
IF(ISTK2.EQ.1)GO TO 0895
WRITE(6,0875)(ELAT2(LL,I),ELON2(LL,I),LL=2,ISTK2)
CCNTINUE
STCP
ENC
FUNCTION RANJ(Y1,X1,Y2,X2)
RANJ DETERMINES THE RANGE BETWEEN (X1,Y1) AND (X2,Y2)
RANJ=SQRT((Y1-Y2)**2+(X1-X2)**2)
RETURN
ENC
MAN04810
MAN04820
MAN04830
MAN04840
MAN04850
MAN04860
MAN04870
MAN04880
MAN04890
MAN04900
MAN04910
MAN04920
MAN04930
MAN04940
MAN04950
MAN04960
MAN04970
MAN04980
MAN04990
MAN05000
MAN05010
MAN05020
MAN05030
MAN05040
MAN05050
MAN05060
MAN05070
MAN05080
MAN05090
MAN05100
MAN05110
MAN05120
MAN05130
MAN05140
MAN05150
MAN05160
MAN05170
MAN05180
MAN05190
MAN05200
MAN05210
MAN05220
MAN05230
SBR00010
SBR00020
SBR00030
SBR00040
SBR00050

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C      FUNCTION DGMN(X)
C      DGMN CONVERTS DEGREES AND MINUTES FROM DD.MM FORMAT TO
C      MINUTES ONLY
C      DGMN=(X-INT(X))*100.+INT(X)*60.
C      RETURN
C      ENC
C      SUBROUTINE KURAJ(PLAT,PLON,RLAT,RLCN,ELNT1,ELNT2,NTCT,DXPOZ,NEOB,
C      1RADN1,RADN2,RL,FM)
C      KURAJ DETERMINES THE EXPOSURE OF A POINT IN THE OPERATING AREA
C      ANC RETURNS IT AS DXPOZ.
C      DIMENSION RLAT(50),RLON(50),ELNT1(50),ELNT2(50),RADN1(50),RADN2(50
C      1),RL(50),FM(50)
C      INTEGER RADN1,RADN2,ELNT1,ELNT2
C      DXPOZ=0.
C      PUKRF=1.
C      ITERATE FOR EACH RADAR IN THE EOB
C      DO 200 I=1,NTOT
C      SEARCH THE PARAMETER TABLE FOR THIS RADAR
C      DO 210 J=1,NEOB
C      IF((RADN1(J).EQ.ELNT1(I)).AND.(RADN2(J).EQ.ELNT2(I)))GO TO 211
C      CCNTINUE
C      CHECK TO SEE IF THE RADAR IS A THREAT RADAR (RL > J)
C      IF(RL(J).EQ.0.)GO TO 200
C      MEASURE THE RANGE FROM THE STRIKE TO THE RADAR
C      R=LANJ(PLAT,PLON,RLAT(I),RLON(I))
C      IF THE STRIKE IS WITHIN THE LETHAL RANGE COMPUTE THE EXPOSURE
C      IF(R.LT.RL(J))PUKRF=PUKRF*(R/RL(J))*FM(J)
C      DXPOZ=1.-PUKRF
C      CCNTINUE
C      RETURN
C      ENC
C      SUBROUTINE ANTDB(GAIN,BEAM,AVGSLL,FREQ,ITRAK,RFACT)
C      ANTDB GENERATES 180 DEGREES OF AN ANTENNA PATTERN. IT IS
C      ASSUMED THAT THE PATTERN IS SYMMETRIC FOR THE OTHER 180 DEGREES.
C      THE APERTURE E-FIELD DISTRIBUTION IS ASSUMED UNIFORM FOR
C      TRACKING RADARS AND FIRST ORDER COSINE FOR EW/ACQ RADARS.
C      DIMENSION BNUL(180),PATRN(180),RFACT(181)
C      PI=.141592654
C      DETERMINE THE WAVELENGTH (WAVE) AT THE FREQUENCY (FREQ)
C      WAVE=299792500./FREQ
C      DETERMINE THE APERTURE DIMENSION FOR AN ACQ RADAR
C      APERT=(69.*WAVE)/BEAM
C      CCNVRT GAIN FROM DB TO LINEAR
C      GAIN=10.**((GAIN/10.))
C      CCNVRT AVERAGE SIDE LOBE LEVEL FROM DB TO LINEAR
C      AVGSLL=(10.**((AVGSLL/10.)))/GAIN
C      IF THE RADAR IS A TRACKER RECOMPUTE THE APERTURE

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SBR000060
SBR000070
SBR000080
SBR000090
SBR000100
SBR000110
SBR000120
SBR000130
SBR000140
SBR000150
SBR000160
SBR000170
SBR000180
SBR000190
SBR000200
SBR000210
SBR000220
SBR000230
SBR000240
SBR000250
SBR000260
SBR000270
SBR000280
SBR000290
SBR000300
SBR000310
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SBR000370
SBR000380
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SBR000400
SBR000410
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SBR000430
SBR000440
SBR000450
SBR000460
SBR000470
SBR000480
SBR000490
SBR000500
SBR000510
SBR000520
SBR000530

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C      IF(ITRAK.EQ.1)APERT=(51.*WAVE)/BEAM
C      PATRN(1)=1.
C      ITERATE FOR 180 DEGREES IN ONE DEGREE INCREMENTS
C      DC 200 N=1,180
C      SET THE VALUE OF PSI DEPENDING ON WHETHER THE RADAR IS A
C      TRACKER OR ACQ TO THE VALUE WHERE THE PATTERN NULLS OCCUR
C      PSI=(N+.5)*PI
C      IF(ITRAK.EQ.1)PSI=N*PI
C      CCMPUTE THE POSITION OF THE PATTERN NULLS
C      BNUL(N)=ARSIN((PSI*WAVE)/(PI*APERT))*57.29577951
C      SET PSI TO THE VALUE WHERE THE PATTERN MAXIMA OCCUR
C      PSI=(N+1)*PI
C      IF(ITRAK.EQ.1)PSI=(N+.5)*PI
C      CCMPUTE THE VALUES OF THE PATERN MAXIMA
C      PATRN(N+1)=(ABS((PI/4.)*((SIN(PSI+PI/2.))/(PSI+PI/2.)))+(SIN(P
1SI-PI/2.))/(PSI-PI/2.)))*2)
C      IF(ITRAK.EQ.1)PATRN(N+1)=(ABS((SIN(PSI))/PSI))*2
C      CHECK TO SEE IF THE PATTERN MAXIMA HAVE FALLEN BELOW THE
C      AVERAGE SIDE LOBE LEVEL
C      IF(PATRN(N+1).LT.AVGSLL)GO TO 300
C      IF THE LOBE POSITIONS ARE GETTING CLOSE TO 90 DEG. GO AHEAD AND
C      SET THE PATTERN TO THE SIDE LOBE LEVEL SINCE TAKING THE ARCSIN
C      OF VALUES GREATER THAN ONE WILL CAUSE AN ERROR
C      IF(BNUL(N).GT.80.)GO TO 300
C      CCNTINUE
C      CCNTINUE
C      BNUL(N+1)=181
C      SET THE VALUE OF THE PATTERN TO THE VALUE OF THE PARTICULAR
C      SET THE INTERMEDIATE PATTERN VALUES TO THE MAXIMUM VALUE OF
C      THE SIDE LOBE WHICH THEY LIE IN TO ELIMINATE THE NARROW NULLS
C      RFACT(181)=AVGSLL*GAIN
C      L=0
C      DC 500 K=1,180
C      N=L+1
C      IF(K.GT.BNUL(L+1))L=L+1
C      RFACT(K)=PATRN(M)*GAIN
C      CCNTINUE
C      RESET THE GAIN TO DB
C      GAIN=10.*(ALOG10(GAIN))
C      RETURN
C      ENCL
C      SUBROUTINE GDPTS(M,N,TEFF,LT,LN,TCTP)
C      GDPTS SORTS THE PERFORMANCES AND RETAINS THE TEN BEST
C      PERFORMANCES AND THEIR POSITIONS.
C      DIMENSION LT(10),LN(10),TOTP(10)
C      DC 500 K=1,10
C      IF(TEFF.LE.TOTP(K))GO TO 500
C      KK=10-K

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SBR00540
SBR00550
SBR00560
SBR00570
SBR00580
SBR00590
SBR00600
SBR00610
SBR00620
SBR00630
SBR00640
SBR00650
SBR00660
SBR00670
SBR00680
SBR00690
SBR00700
SBR00710
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SBR01010

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 SBR01350
 SBR01360
 SBR01370
 SBR01380
 SBR01390
 SBR01400
 SBR01410
 SBR01420

```

DC 400 J=1, KK
LL=11-J
MM=10-J
LT(LL)=LT(MM)
LN(LL)=LN(MM)
TCTP(LL)=TCTP(MM)
CCNTINUE
LT(K)=M
LN(K)=N
TCTP(K)=TEFF
GC TO 600
CCNTINUE
CCNTINUE
RETURN
END
SUBROUTINE ORDER(PRTY, NTOT, NPRTY, ISTK)
ORDER ARRANGES THE PRIORITIES IN DESCENDING ORDER BY
SUBSCRIPTS ONLY. ONLY THE SUBSCRIPTS ARE COMPUTED; THE PRIORITY
ARRAY IS NOT REARRANGED.
DIMENSION PRTY(50,50), PRTEMP(50), NPRTY(50)
DC 1100 I=1, NTOT
PRTEMP(I)=0.
CCNTINUE
DC 1160 I=1, NTOT
K=1, NTOT
IF(PRTY(ISTK, I).LE.PRTEMP(K))GO TO 1150
KK=NTOT-K
IF(KK.EC.0)GO TO 1140
DC 1140 J=1, KK
LL=NTOT+1-J
MM=NTOT-J
PRTEMP(LL)=PRTEMP(MM)
NPRTY(LL)=NPRTY(MM)
CCNTINUE
PRTEMP(K)=PRTY(ISTK, I)
NPRTY(K)=I
GC TO 1160
CCNTINUE
CCNTINUE
RETURN
END
SAMPLE EMITTER PARAMETER TABLE FOR AN ACQ, SAM, AND AAA RADAR.
C ELINT NO. 1 MAX DETECTION RANGE, MAX LETHAL RANGE, P'MAX, M, N
C FREQ, POWER, MAX RANGE, MAX LETHAL RANGE, SIDE LOBE LEVEL, ITRAK, FMOD, , , ,
A100Z 1.5E 09 0.3 0.3 0.6 7. 0. 0 1.0 4.
A200Z 2.5E 09 0.6E 0640. 1.0 5.0 1.0 1.0
  
```


A300Z 3.5E 09 0.4E 0640. 0.3 1.0 0.65 5.0 7. 1 1.0⁴.

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3. Skolnik, Introduction To Radar Systems, p. 264 to 269, McGraw Hill, 1962.

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Thesis

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